AutoBatch™
Chemical Injection System

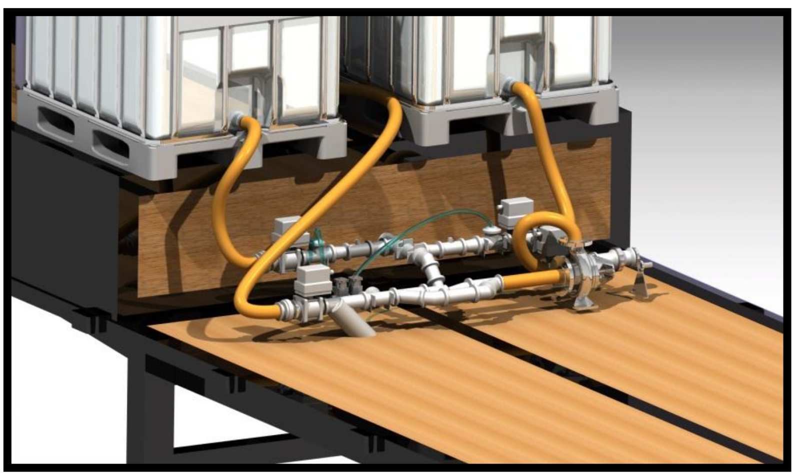
N_2 Line Solutions

Senior Design Capstone Project

Final Report

May 1, 2012

Biosystems & Agricultural Engineering
Oklahoma State University



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AutoBatch™ Chemical Injection System

Abstract

The AutoBatch chemical injection system is an automated chemical tendering station to be used in conjunction with agricultural chemical spray applications. After researching the agricultural industry in its current state, a need for faster, more reliable transfer and mixing procedures was evident. In addition, exposure to toxic chemicals poses a threat to every chemical applicator. The objective of the project was to develop the algorithm and design a conceptual prototype to reduce fill time, reduce handler exposure, and increase batch accuracy for chemical applicators. Project specifications dictated that this product be expandable to multiple chemicals, include a clean in place function, and an automation algorithm that accurately measures injected chemical within three percent error. Industry research was followed by design analysis, component evaluation, and process testing. Component evaluation integrally revolved around piping geometry and valve response time. Component selection was based on loading time goals and response time constraints. The system was automated using a programmable logic controller and a human machine interface. Software development and instrumentation allows the user to initiate the desired batch and run the process to completion. The designed system limits exposure and provides a one thousand gallon batch load in approximately three minutes. The system's clean in place function allows for complete clean out of the system, ensuring total chemical loading and limiting the risk of spillage. Validation of the AutoBatch system was completed through weight comparison by measuring chemical tote and carrier solution volume before and after injection. The system is over ninety-nine percent accurate for all total volumes and presented less than one percent error for chemical injection volume ten gallons and above.

Project Acknowledgments

Design Team—N_2 Line Solutions

Mission

N_2 Line Solutions focuses on providing reliable chemical injection systems for agricultural applications. Our products maximize production and provide customers with the latest technological advancements in the industry.

Figure 1. N_2 Line Solutions. (Left to right: Eric, Collin, Meredith, and Scott)

Client—Microfirm, Inc.

Mr. Kent Dieball

Dr. Marvin Stone

Faculty and Staff

Dr. Glenn Brown	**Dr. Daniel Storm**
Dr. Randy Taylor	**Dr. Dan Thomas**
Dr. Ning Wang	**Dr. Paul Weckler**
Dr. Jason Vogel	**Mr. Wayne Kiner**

Biosystems and Agricultural Engineering Department, Oklahoma State University

Project Introduction

The Biosystems and Agricultural Engineering (BAE) Department at Oklahoma State University (OSU) in Stillwater, OK partners students with professional companies for a collaborative project experience through its senior design capstone course. The class project is completed over the course of both the fall and spring semesters and offers students a real-world, hands-on experience. The automated chemical mixing project was given to four students: Collin Boettcher, Scott Clark, Eric Lam, and Meredith Shiflet. These students, under the direction of Team Leader Scott Clark, formed the unofficial business entity known as N_2 Line Solutions. The group's partnering client for the automated chemical mixing project is Microfirm, Inc. The company is a small corporation that specializes in electronics, automation, and sensing for the agricultural industry. Microfirm was formerly owned and operated by Dr. Marvin Stone; however, the company was recently sold to Mr. Kent Dieball. Dr.Stone remains employed by Microfirm and is a former Oklahoma State BAE Regents Professor. He is renowned for his research and application of in-field sensing and automation in the agricultural industry, such as AIM Command and the Greenseeker technology (Stone, 2012).

The presented project concept consists of developing an automated chemical mixing system for large-scale agricultural applicators. The product should provide a faster refill time and reduce chemical spillage and overall operator exposure. This system should allow commercial applicators to spend more time treating fields and less time mixing up prescriptions. N_2 Line Solutions will execute the conceptual design and prototype testing for the mixing system for the algorithm development. The concept should include a carrier solution with at least two chemical additives. Once the desired chemical volumes have been selected, the mixing system should operate a series of automatic control valves based on flowmeter readings to deliver the desired amount of chemical products in the proper sequence as requested without a batching tank. The team will use an Allen Bradley programmable logic controller (plc) to monitor flow and control the electric components within the mixing system. The team should also develop a modest input console to provide validation of the system's accuracy at the conclusion of the project. Once the concept has been perfected, Microfirm will utilize the design recommendations and manufacture a full-scale system. Development should eventually allow this platform to be able to communicate to a Virtual Terminal (VT) within a spray rig to select the batch and record the load via CANBUS or potentially become operational through a mobile device application.

Problem Statement

Commercial chemical applicators spray hundreds of acres daily, but they can spend up to twenty percent of their time mixing chemicals and filling their spray rig solution tanks. N_2 Line Solutions has partnered with Microfirm, Inc. to develop an automated batch chemical mixing and loading system. The proposed concept would help reduce fill time and contain a clean in place function to help alleviate the risk of human exposure to chemicals. The automated fill system must be user friendly, consistently provide accurately mixed batch chemical loads of all sizes, record and summarize the dosage calculations, and be cost effective for the end user.

Statement of Work

Microfirm, Inc. expects N_2 Line Solutions to devise an automated chemical mixing and dispatch platform prototype concept to be used in conjunction with a nurse trailer or filling station. The automated system will meter and dispense chemicals based on the inputs entered in the electronic human interface on the system, inject the chemicals into the carrier solution line filling the sprayer, and rinse the chemical subsystem to avoid contamination of subsequent batch loads. Although the primary goal of the project is to develop a conceptual design and formulate an algorithm, the team should also make final recommendations for the proposed mixing system's design. The recommended platform will house the entire system, deliver a 1200 gallon batch load in less than five minutes, and have the capability to incorporate granular products via an inductor. The design should allow the operator to transfer batch loads without switching chemical transfer pumps between totes, and thus reduce chemical waste, time, and extra labor costs. N_2 Line Solutions will conduct component verification and design testing throughout the spring semester to develop the algorithm. A conceptual design will be presented along with accuracy validation results and product design recommendations in May of 2012.

Project Scope

This project focuses on developing the proof of concept prototype for an automated chemical mixing system. Not only should the system allow for accurately measured chemicals to be injected into the streamline of the carrier solution, the system should also allow for manual chemical addition via an inductor. This system will reduce handler chemical exposure and provide a means to log and transmit chemical batch concentrations and information. The original concept expectations and requirements set forth by Microfirm, Inc. are shown in Table 1.

Table 1. Initial project expectations outlined by Microfirm, Inc.

Microfirm, Inc. Proof of Concept Requirements	
1)	Reduce the time required to manually re-fill the sprayer tank.
2)	Prevent chemical spillage.
3)	Assure ingredients are added in the correct order and amount.
4)	Minimize exposure of operators to agricultural chemicals.
5)	Provide an economical automated system to agricultural chemical applicators.
6)	Determine the best pump setup to draw water and chemicals into the sprayer during refill.**
7)	Utilize "Off-the-shelf" valves, metering devices and control components.
8)	Demonstrate a proof of concept design by accurately injecting two products into the carrier solution.
9)	Validate the batch concentration delivered by the fast-fill system. 7% error is acceptable.
10)	Provide a rinse function to assure lines can be rinsed as needed to reduce contamination.
11)	Determine which chemicals and products are most commonly used for Midwest wheat production.
12)	Provide conceptual reference for a central operator interface to enter amounts for each ingredient.
13)	Provide "Start" button to run process to completion and an interrupt button to stop the fill process.
14)	Deliver reasonable assurance that the system meets any applicable EPA and or OSHA requirements.
15)	Research, identify competitive products, and provide a design that does not infringe on any known patents.

Concept Deliverables

After reviewing the project expectations and goals of the mobile automated chemical mixing system, the group met with Mr. Dieball and Dr. Stone to discuss the conceptual development and design expectations. The two parties determined the project should focus more on the conceptual development and not a final product and therefore, the project requirements were adjusted. Due to the complexity of the automation and the electrical components involved with this project, it was deemed unrealistic for the team to construct a complete platform and full scale model that transfers up to 350 gallons per minute of carrier solution while adding chemicals. Not only would that be an expensive prototype to create, but it also presented logistical and product validation issues. A conceptual proof of the design allowed the team to utilize more components already owned by the BAE department. Additionally, smaller tanks owned by the department were used and prevented the team from having to borrow commercial applicator equipment to validate the system. In order to make the project affordable to the client and achievable by N_2 Line Solutions, the conceptual requirements of the design and project were amended as shown.

Table 2. N_2 Line Solutions project requirements.

N_2 Line Solutions Deliverables		
1)	☑	Design and provide a conceptual proof for a quick re-fill chemical mixing station that reduces chemical exposure to the handler.
2)	☑	Develop a system that utilizes off-the-shelf components to accurately sequence and inject chemicals into the carrier solution on the station.
3)	☑	Research and identify any competitive products, and provide reasonable support that the design does not infringe on any known patents.
4)	☑	Deliver reasonable assurance that the system meets any applicable industry EPA and/or OSHA requirements.
5)	☑	Determine which chemicals are most commonly used for Midwest wheat production and provide a list of those products.
6)	☑	Develop an algorithm to automatically and accurately meter and inject chemical products during a batch fill based on user inputs.
7)	☑	Provide a rinse function to dilute and cleanout the system to reduce chemical contamination.
8)	☑	Provide an input console containing a start button to run the process and an interrupt button to stop the fill process.
9)	☑	Inject products into the system and verify volumetric accuracy within 3%. If not attainable, provide documentation why.
10)	☑	Demonstrate a conceptual proof of the design by running a batch at the system's maximum total capacity and verifying total accuracy within 3%.
11)	☑	Demonstrate a conceptual proof of the design by running a batch load with a small product rate based on the chemical list and verify accuracy within 3%.
12)	☑	Provide a copy of the project report including research conducted, test results, and supporting materials.
13)	☑	Provide the algorithm depicted as a text document and include the programming flowchart.
14)	☑	Deliver a schematic with the testing results for the conceptual proof and provide design recommendations for the final design.
15)	☑	Devlop a projected budget and bill of materials needed to produce the recommended design.
16)	☑	Issue a simple manual or pamphlet depicting the system and how the program is operated.

**All defined objectives were met by the design team.*

Location of Work

The automated chemical mixing system proof of concept was completed by N_2 Line Solutions for Microfirm, Inc. as part of the BAE capstone program. The work was conducted in the BAE lab shop on the OSU campus in Stillwater, OK. Additionally, the team did a large part of their system testing and validation at the BAE Annex in Stillwater due to the number of projects in progress and limited space at the BAE shop. The team also utilized the BAE computer lab in Agriculture Hall on the OSU campus and Senior Design Lab in the BAE lab shop for research and data analysis. The programming and software development was done remotely on a designated laptop provided by advisor, Dr. Paul Weckler. Necessary fabrication was completed in the BAE lab shop or by lab manager, Wayne Kiner and his staff as needed.

Schedule of Work

N_2 Line Solutions broke the work schedule down into two semesters with deliverables and deadlines outlined for both the fall and spring semester. The breakdown for each semester is shown in the following two sections and the full Gantt chart is attached in the appendices.

Fall Semester

Much of the fall semester was dedicated to forming a team, learning about the project, interacting with the client, gathering product information, and researching competitive products. N_2 Line Solutions also observed the fall semester coursework deadlines as outlined in Table 3. This included the formal project proposal to Microfirm at the acceptance meeting in December where the team presented research, assessed prototype testing results, proposed component specifications, product plans, a budget, and a detailed plan for the spring semester.

Table 3. Fall course tasks.

Fall Semester Requirements	
Deliverable	**Due Date**
Team Leader	Sep 09
Team Name	Sep 12
Team Logo	Sep 19
Mission Statement	Sep 28
Problem Statement	Sep 30
Research Outline	Oct 03
Test Plans	Oct 17
Project Research Report	Oct 21
Statement of Work	Oct 28
Schedule of Work	Oct 31
Final Report Submission	Dec 08
Final Presentation	Dec 08

Spring Semester

N_2 Line Solutions emphasized component testing to start the spring semester. Numerous test stands were constructed and used to understand flowmeter accuracy as well as develop the calibration curves needed for the prototype system's flowmeters. The flowmeters used were borrowed and did not contain calibration numbers from the manufacturer. In addition, the team also conducted many trials to determine the most feasible alternative to compensate for the automated control valve response time. Calculations were completed to analyze the capacity and constraints of the system prior to building the prototype. The team also conducted design tests with various configurations and eventually configured components to mock up a conceptual proof of the proposed automated fast-fill chemical mixing system. Numerous tests were conducted to improve the algorithm and the overall chemical injection precision. Hundreds of hours were spent testing, collecting data, developing the software, configuring hardware, and validating the system's effectiveness for minimal chemical injection error. The validation stage was a critical phase of the project in order to understand the goals achieved as well as what potential problems may arise in the field application of the product. The team provided documentation of the conceptual design, as well as recommendations for the future prototype station at the April presentation. The team also delivered a copy of the report, text of the algorithm, a program flowchart for algorithm and software development, and a list of materials for the design to Microfirm. The client produced the recommended station and will further develop the algorithm for large scale application throughout summer 2012.

Table 4. Spring academic deliverables.

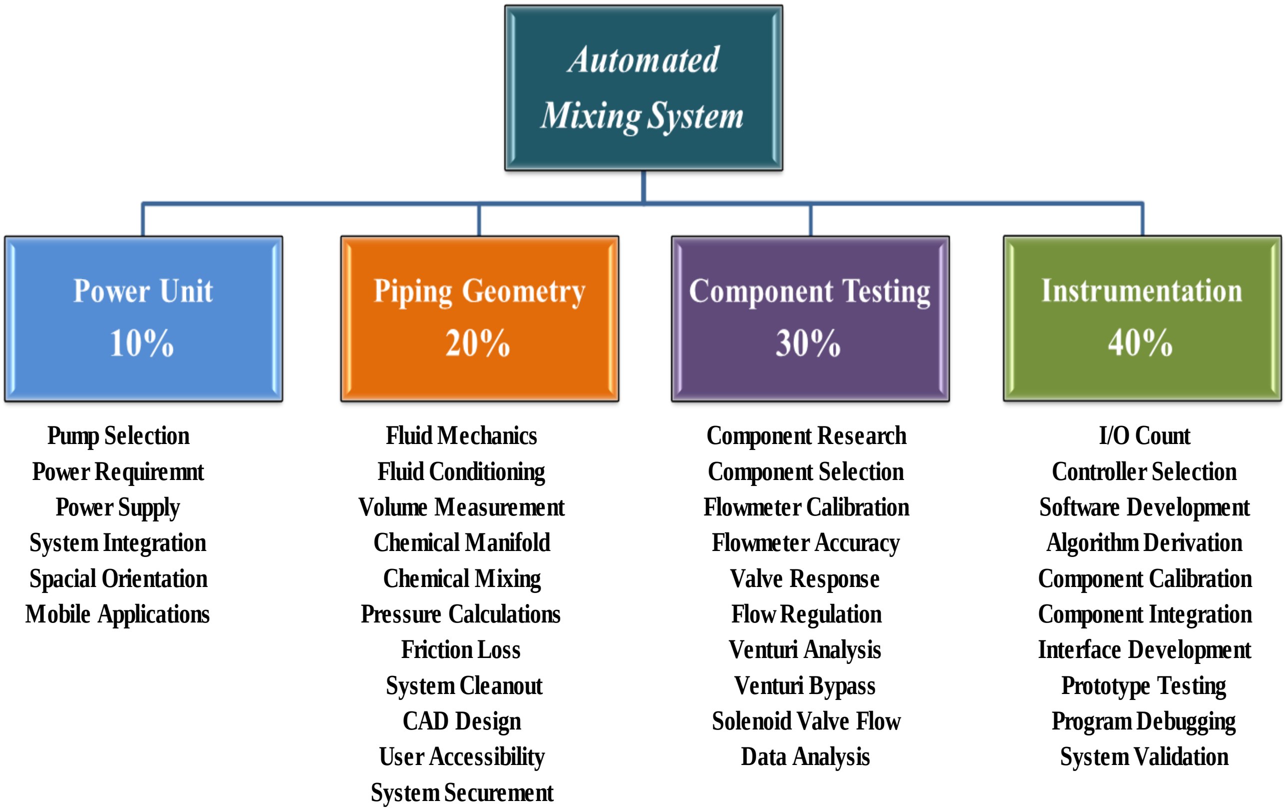
Spring Semester Requirements	
Deliverable	**Due Date**
Revise Gantt Chart	Jan 13
Document Deliverables	Jan 13
Finalize Concept Design	Jan 23
Order Major Components	Jan 26
Revised Statement of Work	Jan 27
Order Major Components	Jan 30
First Rough Draft	Mar 12
Fabrication Completion	Mar 26
Second Rough Draft	Apr 02
Testing Completion	Apr 09
Preliminary Presentation	Apr 16
Room Preparation	Apr 23
Final Report Submission	Apr 26
Final Presentation	Apr 26

The following list represents the main tasks set forth and conducted by N_2 Line Solutions for the fall and spring semesters.

- Team Overview
- Client Orientation
- Mission Statement
- Problem Statement
- Statement of Work
- Competitive Research
- Technical Research
- Testing and Experimental Data
- Design Concepts
- Industry Analysis
- Design Acceptance
- Component Purchasing
- Hardware Configuration
- Calibration and Assembly
- Prototype Testing
- Design Modifications
- Algorithm Construction
- Software Development
- Program Debugging
- Product Validation
- Proposed Budget
- Design Recommendations

Work Breakdown Structure

N_2 Line Solutions separated the automated chemical mixing system project into four categories as shown in the following breakout: power unit, piping and layout geometry, component testing, and instrumentation. The team discovered that the power unit options were limited due to the loading time goals of this project. The team analyzed different motors and pumps to be used for the recommended platform. Next, the team spent many hours configuring the most efficient and proper way to plumb the system and eventually a pictorial view of the design was rendered using Catia. The next category was component and process testing for component selection and recommendations as well as algorithm development. The final and most critical stage was compiling the testing results and system layout in order to automate the entire chemical batching process. A condensed Gantt chart is shown in appendix A.



Resources and Suppliers

N_2 Line Solutions' suppliers are primarily in the agricultural, electrical, plumping, plastics, and chemical supplier industries. N_2 Line Solutions utilized as many components and fittings available to them through the client and the BAE department for the conceptual proof to reduce cost. However, the final design recommendation was based on what the team determined necessary by the engineering design process, not by what was necessarily readily available for during prototype development. The team utilized Raven flowmeters and electric valves provided by the department. The design team also borrowed an Allen Bradley programmable logic controller (plc), an oscilloscope, a function generator, a high frequency counter, a Dell laptop, a circuit protoboard, electrical harnesses, cables, and various resistors, transducers, op-amps and general circuitry components from BAE. The BAE department provided an RSLogix 500 software starter program to the team and the license was renewed. Many of the electrical components and parts were borrowed from Dr. Ning Wang's lab at the BAE lab shop.

The water pumps and motors, as well as suction hoses, for testing and system validation were borrowed from Dr. Dan Storm, BAE professor. The carrier solution storage tanks were borrowed from Dr. Randy Taylor and the BAE department. Industrial Bulk Containers (IBCs) were borrowed for the duration of the project from Matt Steinert of Covington, OK and returned at the conclusion of the project. The client determined that a human interface should be developed for the project on a PC to allow for an input console to test and validate the system. Dr. Taylor and Mr. Kiner designated a bank of Banjo fittings and connectors that could be used for the project. Dr. Stone provided the team with several Raven flowmeters and wiring harnesses to use for project testing, and perhaps the final product. The team purchased any additional Banjo fittings and valves or Raven flowmeters from Schaben Industries of Newton, KS as needed (Schaben, 2012).

N_2 Line Solutions suggested the following suppliers for the final product to Microfirm: Federal Corporation of Oklahoma City, OK for schedule 80, Drisco PVC pipe for the final design. In the event that the final design exceeds an I/O count of 14, a larger microcontroller can be purchased from Rockwell Automation (Rockwell, 2011). Based on price and availability, the team suggests that the client utilize Schaben Industries for gas engines and pumps for the final design. Most of the steel for platform construction, electrical wiring, wiring protection, and connectors can be sources from any desired vendors.

Acceptance Criterion

Microfirm's approval and acceptance of the suggested project was N_2 Line Solutions' utmost concern. Microfirm provided initial constraints and requests to guide the project, but ultimately N_2 Line Solutions tested components and constructed the system based on research and testing results. The team focused heavily on refining an efficient process during the design development phase. The general system layout and setup of the final product is important for customer appeal, but it can also affect instrument accuracy. In order to further develop these constraints, the team conducted tests to provide answers for improving injection accuracy and automation for the algorithm development of the project. Once the component tests were completed and the design selected, the instrumentation and component integration phase of the automated project was given intensive attention in order to dial in the system specifications and improve the level of accuracy.

The client requested that the product must be functional and reliable in terms of consistency and accuracy. It must meter and deliver chemical within plus or minus three percent of the desired product input no matter the size of the batch's chemical or carrier volume. The system must use a programmable logic controller (plc) to control the components independently based on the designation of the batch prescription at the input console. The design must also provide a rinse function to reduce chemical residue in the system and avoid future batch contamination. Validation of the system was exhibited at the conclusion of the spring semester. The client requested at least two batches be completed for validation—one batch was run at full system capability while the other batch consisted of a small, specific batch size. All chemical volumes within the batches were validated based on the flowmeter reading and the differential weight of the chemical tote. Microfirm was very pleased with the amount of intensive testing and data collection completed in the development stage of this project. Additionally, the client was very satisfied with the consistency and high level of accuracy of the product's ability to produce requested batch loads. Further design recommendations were provided and N_2 Line Solutions satisfied all requirements of the project for Microfirm, Inc.

Target Customer

The automated batch chemical mixing system is designed for customers operating spray rigs with 90 or 120 foot boom widths and 800-1200 gallon solution tanks. These self-propelled or pull-type rigs are typically utilized by large producers or commercial applicators that need to cover a lot of ground in a short amount of time. The machinery has the capability to meet applicators' needs, but the time required to mix chemicals and refill the sprayer is usually around 12-20 minutes depending on the batch formulation and is detrimental to the operation's production. In addition, most of these larger applicators are familiar with technology and would be most susceptible to an automated tendering platform. This product would allow the end user to save time and money while creating an opportunity to perform additional work each day. The primary tendering scenarios are commercial applicators and cooperatives using one trailer to transport carrier solution, a tendering station, and a sprayer. Another scenario is using a nursing trailer to transport carrier and a tendering station while the final target is customers using a transport trailer to move a tendering station and chemical in conjunction with a mobile and field tank for the carrier solution supply.

Figure 2. A commercial applicator or cooperative transporting a sprayer, mixing station, and carrier solution tank.

Figure 3. Large producers using nurse trailers with carrier solution tanks and mixing area.

Figure 4. Farmers using utility trailers (Dan D, 2012) for chemical mixing used in conjunction with a mobile field tank or bulk water tanker (Portable Tank, 2012).

Industry Overview

An automed batch mixing system allows applicators to improve the tank mix accuracy, reduce the time required to complete their application activities, and transfer chemicals with less chemical exposure. Improved chemical dosages and increased productivity become even more important as the number of applicators and the number of acerage sprayed annually increases. In 2004, Oklahoma producers applied 267,000 lbs of herbicides to 34% of cropland. Yet, in 2009, that number grew to 53% and over 2,359,000 lbs of herbicides. This shows that not only are Oklahoman agriculturists utilizing herbicides on a growing number of acres, they are also applying an increased rate annually per acre. Environmentally, the industry needs ways to help monitor the amount of chemicals being applied to every acre to ensure the proper dosages are being used. Oklahoma is just one of thirteen Midwest states that have increased herbicide applications in the last decade. From 2004 to 2009, Kansas experienced a 13% increase in annual cropland herbicide applications with an increase in chemical usage totaling more than 437,000 gallons. (NASS, 2010)

In 2009, no-till practices occurred on 35% of all the acres planted to the eight major crops: barley, corn, cotton, oats, rice, sorghum, soybeans, and wheat. (NASS, 2010) As more and more producers turn to no-till and minimum tillage practices instead of conventional tillage, the number of acres requiring herbicide applications also increases (Agmanager, 2010). Many Oklahoma wheat producers apply a burndown herbicide two or three times during the summer. Additionally, the same producer will apply a broadleaf control herbicide in the spring while topdressing with a nitrogen fertilizer. These four applications on each wheat field combined with more intensive applications on rotational row crops have grain producers applying more chemicals than ever before. This management strategy has caused many commercial applicators to gain clients resulting in the demand to cover more acreage in the same amount of time. Custom applicator fees are $4-$5 per acre for each application and many of these cooperatives or commercial applicators have trouble covering the increased acreages, so larger producers are purchasing their own sprayers to apply chemicals to their own crops. Although this is an economically feasible scenario in most cases, it creates an extra time consuming task for the producer. Reducing the time required to complete applications can be must affected by reducing the re-fill time.

Buyer Research

According to Iron Solutions, sprayer sales increased by more than 65% from 2007-2009. Improvements in technology and design have made owning a self-propelled sprayer more feasible for individual producers. What was once considered a task only for large, specialized operators and commercial applicators is now available to the average farmer. According to Farm Industry News, "Hagie Manufacturing has already booked and sold all of this year's sprayers that they can produce." (Penton, 2012) Other major manufactures such as AGCO, John Deere, New Holland, and Case IH are also producing and shipping sprayers at rapid rates.

Agriculturists are looking for avenues to increase their application efficiency and their overall number of acres sprayed daily. Although a large spray rig traveling at fifteen miles per hour with a 120 foot boom can cover over 200 acres per hour, most sprayers can only carry 1200 gallons of solution instead of the 2000 gallons it takes to keep up with the machine covering 200 acres. Adding larger tanks to sprayers requires more power due to the increased weight of the rig, causes increased soil compaction, and can potentially reduce operator visibility. An alternative to the problem is reducing the refill time to help increase the field operation time. The demand for increased productivity has caused some agricultural application manufacturers to produce mixing equipment that will help reduce filling time, but a completely automated fast-fill system has yet to be seen.

These sprayers are also bringing a tremendous amount of technology with them and most producers can see the benefits a precision system offers. Developments such as RTK guidance, electronic nozzle manipulation, and improved nozzle tips mean dramatic increases in efficiency. As this technology becomes more available at affordable pricing, some farmers can expect to pay off their investment in approximately two years (Reibel, 2010). Rather than paying and depending on a commercial applicator, a farmer can make the same payments towards their own equipment and time applications more effectively. As the number of acres sprayed and number of sprayers continues to increase, the market for a fast and efficient intermediate chemical shuttle will grow dramatically.

Market Analysis

N_2 Line Solutions has designed an automated, mobile chemical mixing shuttle on a compact platform. This design allows the user to easily transport it and operate the entire automated process from the central Human Machine Interface (HMI). An automated system is more beneficial than a traditional system because it allows for multiple activities to be occurring at the same time with just one operator. Whereas a manual system requires more filling time and two, or even three workers to do the same job that one operator can do with an automated system. Not only does this system reduce the labor involved and the time invested, it also protects the users as well. The automated system allows the operator to push a button to select the desired chemical the chemicals are transferred from their holding containers through the closed system and into the sprayer without the operator ever having to handle the product. Many applicators currently use a transfer pump on top of the product container and pump chemical into a mixing tank. Moving the transfer pump between products can spill chemical all over the work area and the user. Some chemicals, such as Paraquat or Gramoxone, are toxic to humans and have no identified antidote. Upgrading to an automated chemical handling system could potentially save someone from ingesting a toxic chemical.

As opposed to similar mechanical systems on the market, the automated system would come pre-assembled and will be versatile in order to encompass the needs of a Kansas wheat farmer, a Texas cotton farmer or an Iowa corn farmer. Minor changes to the assembly will allow each user to customize the platform to his or her needs, but eliminates the time and knowledge required to build an intricate system from scratch. An automated chemical mixing system can save applicators at least several minutes at each fill up. Depending on the current system used, an efficient, automated system could save up to ten hours of fill time over the course of one week. Applicators often have narrow windows of time to get chemicals applied due to weather or agronomic conditions. Reducing fill time reduces the overall time required to complete the spraying task and will allow producers to do more than ever before in the same narrow windows presented to them. If utilized effectively, an automated system could help save a producer thousands of dollars by allowing him or her to get more done each day. Finishing applications faster means getting a field completed sooner before a storm arrives to wash chemical away or prevent field entry all-together. Helping applicators reduce the fields that have to be re-sprayed not only helps save farmers money, it also helps protect the environment.

An automated system also presents environmental benefits due to accurately mixed chemical loads. When chemical dosages are not mixed correctly, excess chemical will likely contaminate local bodies of water. However, if the chemical dosage is not high enough, the field may have to be re-sprayed for proper results. The automated station allows operators to enter the desired chemical rate per acre and calculate the total volume needed for the batch load. The software then asks the user to verify the amounts before the batch is loaded to help ensure the proper volume is transmitted. Additionally, the system utilizes flowmeters that have one to two percent accuracy and the algorithm instructs the chemical valves to shut as the meters reach the proper volume. Although the system is no more accurate than the accuracy of the flowmeters, the software provides the monitoring of the measured fluids and delivers the commands to the components with 99% consistency. Lastly, if a producer has considered increasing boom width from 90 feet to 120 feet to increase productivity, but is concerned that the fields are not big enough to support 120 foot booms, a faster fill station may be the solution. This system could offset the difference between the boom sizes without ever having to trade to larger equipment.

Regulations & Standards

The main source of regulation within the chemical industry is provided through the United States Environmental Protection Agency (EPA). Comprehensive data is available through the EPA for each state's specific regulations. There are two main federal laws governing the distribution, use, and disposal of pesticides: the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). Many of these regulations overlap and interact to provide adequate regulation for the pesticide industry. Most states also provide chemical application restrictions for certain products or seasons (OAFF, 2012).

The FIFRA mandates that all products be licensed and registered with the U.S. EPA before production and distribution. This legislation also standardizes labeling, packaging and disposal procedures while providing for situational emergency use which may violate standard procedures. Special application exceptions may be granted when there is a risk of substantial financial loss or harm to endangered species or other negative environmental impacts. The EPA also has authority under FIRFA to remove a products approval at any time and gives proper procedures for appeal. The EPA has issued a Label Review Manual (LRM) which aids in the interpretation and creation of chemical labels. Deviations from the standards presented in the LRM are considered violations of FIRFA. The LRM details every aspect of pesticide labeling process including but not limited to ingredient listing, hazard warnings, personal safety and handling, directions for use and manufacturer contact (USEPA, 2012).

The FFDCA mandates the safety and tolerances of pesticide use as it pertains to food or livestock production. The procedure for establishing and regulating application tolerances and standards mandates that all levels must never reach a level where they are likely to cause harm or loss of life. Residual pesticide tolerances within food products are further regulated by the Food and Drug Administration; FFDCA specifically focuses on the production process. Additional legislation includes the Pesticide Registration Improvement Act (PRIA) of 2003 which further regulates the registration of chemicals into three distinct categories (USEPA, 2012).

Regarding storage and disposal of pesticides, FIRFA as well as the Resource Conservation and Recovery Act (RCRA) ensure responsible management of chemicals. Most states have instituted programs specifically for agricultural producers for proper chemical disposal. State extension resources are available through the EPA Pesticide Storage Resources section. The Clean Water Act also regulated pesticide tolerances and how they relate to water quality. This greatly impacts where, how and under what conditions a chemical may be applied in order to minimize environmental impacts (USEPA, 2012).

The ISO 11783 Virtual Terminal protocol was created by Dr. Marvin Stone in order to bridge the communications gap between equipment produced by all manufacturers. The idea to use VTs allows the “operator to switch to see either a drill or sprayer” produced by two different manufacturers on the same monitor. This system was created in 2000 and has since been integrated with modern precision agriculture equipment and supported by equipment manufacturers such as AGCO, John Deere, and Case IH. This protocol formalized to the ISOBUS Standard 11783 in 2006 (Stone, 2012). The Agricultural Industry Electronics Association (AEF) is an independent international group dedicated to coordinating the development of electronics, technology, and improvements for farm machinery. The group works to enforce protocols and regulations such as ISOBUS (AEF, 2009).

The ISOBUS protocol was acknowledged by the team because it is a standard that the mixing system must adhere to in order to communicate with an applicator rig's VT. It is beyond the scope of N_2 Line Solutions' project to equip the platform with ISOBUS, but utilizing a virtual terminal system is a potential goal of the client to be pursued if desired. Cheaper, more readily-available software platforms and controllers were used for the prototype development.

Publications and Visibility

Resources for chemical applicators are quite varied and specific to location. The American Society of Professional Pesticide Applicators (ASPPA) provides national and state opportunities for education, networking, and resources. Online training and study classes are available for certification and additional development. The Soil and Water Conservation Society (SWCS) is a national organization that provides training and information to improve water quality and conservation practices. Information on the certification of training to be a legal chemical applicator is available through the EPA. Most agricultural based universities have extension offices directed towards serving the public with technical assistance. The Oklahoma State Extension office offers training, seminars, as well as general information readily available to the public (OCES, 2012).

One of the biggest scenes for new agricultural products is farm shows and trade show conventions. These shows get new products in front of potential customers and allow them to see, and often use the product. N_2 Line Solutions recommends that Microfirm take advantage of these shows to test the market for this type of product and to get feedback on potential areas of concern. Another marketing tool that helps sell product to target customers is literature, pamphlets, and magazines available at equipment dealers and repair shops. These sources promote the product by raising awareness and product identification. The information should portray how the product will fulfill the current needs of the customer while reducing fill time and labor costs, increasing application times in tight environmental windows, and increasing the producer's bottom line.

Market Transition

N_2 Line Solutions has provided a fast-fill chemical mixing station with cutting edge technology. While this technology is in its infancy, N_2 Line Solutions and Microfirm must help to make it easy to understand and operate in order for best market reception. To help this product transition into the marketplace and be used by producers right away, N_2 Line Solutions first acknowledged the current needs of the end user. The team also followed the product requirements closely and delivered an innovative product that satisfies Microfirm's requests. This product should ultimately allow an applicator to pull a sprayer up beside the platform, select the chemicals and volumes for the tank mix, determine whether a system rinse is necessary, verify the tank mix selected, press start to begin filling the sprayer with the load, record the totals loaded onto the rig, and return to the operator's station in a matter of minutes.

The client has the opportunity to expand the technology for the future industry direction, and integrate the product into VTs currently mounted in sprayers. Technology has changed continually and has not always been initially welcomed in agriculture, but just as yield monitors made their way into combines and auto guidance systems made their way into all farm equipment; N_2 Line Solutions expects functional, automated batch chemical mixing shuttles to take off as well.

Although the economy has been suffering as of late, the agricultural commodity prices have remained attractive. This will help Microfirm market and sell a more expensive chemical mixing platform, particularly if it can produce accurate batch mixes, reduce refill time by 300% and provide a safer environment for chemical handlers. The development of this product should take one year and the product should be available to the market in the fall of 2012. However, algorithm development and updated process and sequence automation should continue for two years to better adapt the program and algorithm for application diversity. Microfirm should not develop an expansion plan until the product success and market viability have been proven in the first year of development. The company should develop a dealer network with a partnering trailer manufacturer to produce, assembly, and distribute the stations.

Competitive Products

The industry depicts a need for a faster way to transport chemical batch loads to application rigs, but research shows there are very few chemical mixing systems on the market that can load a sprayer with chemical and carrier in under ten minutes. There are no commercial mixing systems available that are completely automated.

Some manufacturers, such as JD Skiles, have devised a mechanical system that works very well. The company currently produces one Pit-Stop batch mixing system, as shown in Figure 5, every ten days and has sold fifty in the past year but they claim business has expanded as their product has dispersed throughout the Midwest, and as more applicators have found out about their product. This is one of the more elite systems on the market because it provides users the ability to incorporate up to five chemicals in addition to those slurried in the inductor. The volumetric system is appealing to applicators because it allows them to see the amount of chemical injected into the solution versus relying on a calibrated flowmeter. Some producers reported changing flowmeters every two seasons because they begin to see a decrease in accuracy of the flowmeter. However, the Pit-Stop's tank volume indicators are only guaranteed to be accurate for ¼ - ½ gallon depending on tank size. Additionally, the operator must partially close the valve filling the tank with chemical to slow the flow rate in order to ensure the volume reaches the designated fill mark. Although JD Skiles has developed a mobile system that works well, the system is still tedious work for the operator(s) to maintain and control accurately. Each of the valves is operated manually and the chemicals are pulled from the totes using pump suction and a venturi to create a vacuum. The primary system is comprised of a 13 horsepower, 3" pump and hoses while the secondary system and chemical incorporation tanks are 2" hoses and pipes (JD Skiles, 2011).

Figure 5. The JD Skiles pit-stop platform uses a volumetric measuring system.

The Kahler agricultural monitoring system automates chemical flow using a central interface, but does not contain the whole process from chemical mixing to delivery of the batch to the sprayer.

The system is designed to interface with controllers or flowmeters and is often used in conjunction with a batch system for the agricultural application. Typically, producers use the system to monitor chemical volumes and disperse them to a mixing tank prior to loading the batch onto an applicator. Most of the Kahler systems, Figure 6, available are designed for operation within an enclosed environment such as a warehouse and are not robust enough to be used in a mobile application.

Figure 6. The Kahler system could be used within a system to automate chemical flow.

Another product on the market that has gained a lot of attention is the LoadCommand system sold by John Deere Company. The system utilizes an upgraded pump on the sprayer and unique tender arm mounted on the nurse trailer. This combination provides an easily accessible nurse rig filling point that connects to the front of the spray rig. This system requires an upgraded sprayer pump and a tender arm mounted on each trailer or nurse tank delivering the carrier solution to the sprayer. This package is estimated to cost up to $25,000. The operator hooks the arm shown in Figure 7 to the sprayer to begin the fill process, but the operator can add chemicals to the load through the sprayer's eductor or return to the cab of the unit. Once the desired volume has been reached, the pump shuts off and the single point fill hookup releases itself so that the operator can back away (John Deere, 2011).

Figure 7. The John Deere tender arm and front hookup.

Although this system features an expensive pump upgrade on the sprayers, very few chemical loads can be premixed and sucked onto the sprayer due to foaming that occurs at high flow rates. Additionally, pre-mixed solutions have the opportunity to settle out in the supply tank while waiting for the sprayer to fill each time. This settling reduces the chemical efficacy and also presents environmental risks if a particular portion of a load becomes too concentrated with a chemical. Thus, most users only use the LoadCommand setup when adding a carrier solution such as top-dressing with liquid fertilizer on crops where little or no other products are used. So, this system does allow the fill time to be reduced, but it does not address the hazardous and time consuming manual chemical addition phase of the loading. In addition, the customer is paying $25,000 for a 400 gallon per minute pump and a tender arm whereas a transfer hose and 13hp motor and 3” pump currently used costs just $2000.

The next product N_2 Line Solutions reviewed offered yet another approach to chemical injection. The Raven Sidekick Pro system depicted in Figure 8 mounts onto the application sprayer and injects chemical directly into the hose that delivers the carrier solution from the tank to the boom. The injection system features a 24 gallon tank, a metering device, and a positive displacement pump that delivers the product (Raven 2011). This system only allows one chemical to be added and it also presents some application rate restrictions. If a sprayer has a 1200 gallon solution tank and it is applying 10 gallons per acre, the maximum chemical rate available without refilling the chemical tank before the solution tank is 25 ounces per acre using the Sidekick Pro. This poses a problem as the average application rates for common herbicides such as Glyphosate, Brash, and 2, 4-D Amine is 32 ounces per acre.

Figure 8. The Raven Sidekick Pro.

N_2 Line Solutions concluded that there were no competitive products available on the market in America that offered both an automated process and a complete mixing system station capable of producing the rates and volumes required by Microfirm. However, N_2 Line Solutions found some advantage to the LoadCommand system that offers an on-board, high speed solution pump and a system that can unhook itself remotely. Although the latter feature is attractive, that benefit is estimated to cost a minimum of $25,000 and dealer demo reviews show that the hookup still leaks as much, or more, than a manual system. The team determined that such an option was outside of the scope of the project, but admits that this system is a step in a good direction for the spraying industry and mirrors some of the same goals N_2 Line Solutions has for an automated batch chemical mixing system.

Instead, N_2 Line Solutions has developed an automated process to assist farmers with mixing chemicals to fill a sprayer with a batch load automatically. The desired chemicals are connected to the system and the required volumes are entered into the human interface. Upon selection of chemicals and an optional rinse cycle, the system asks the operator to confirm the inputs and start the process. The system also allows users to manually add or slurry chemical products while the carrier and chemicals are being added to the system. The system decreases the overall amount of time it takes to fill the sprayer with chemical and the carrier solution by as much as ten minutes when compared to high performance manual systems. The versatility of this robust product will allow the system to be used in many agricultural applications with a variety of tank mixes.

The following Table represents the capabilities of each of the competitive products compared to the product goals of N_2 Line Solutions. Although, the projected selling price for N_2 Line Solutions' AutoBatch platform is much higher than other products on the market, there is no competition that is offering the refill speed, reliability, and complete package flexibility of the automated mobile system.

Table 5. Competitive products analysis.

Product Evaluation							
Feature	**Manual System**	**Pit-Stop**	**Kahler**	**LoadCommand**	**Sidekick Pro**	**BatchBoy**	**AutoBatch**
Cost	$5,000	$9,500	$5,000	$25,000	$7,200	$4,840	$25,000
Complete System	Yes	Yes	No	No	Yes	Yes	Yes
1200 Gal. Refill Time (min)	15-20	10	10	5	2	2	5
Metering	Optional	Volumetric	Flowmeter	Volumetric	Flowmeter	Preset	Flowmeter
Auto Shutoff	No	No	Yes	Yes	No	No	Yes
Clean In Place	Optional	Optional	No	No	No	No	Yes
Chemical Capacity	Unlimited	Unlimited	Unlimited	None	24 Gallons	75 Gallons	Unlimited
Mobile System	Yes	Yes	No	Yes	Yes	Yes	Yes
Human Exposure	Yes	No	No	No	No	No	No
Chemical Injection	Yes	Yes	Yes	No	Yes	Yes	Yes
Number of Injected Products	Unlimited	Unlimited	Unlimited	No Chemical	1 Chemical	1 Chemical	Unlimited

After developing the automated chemical injection system, N_2 Line Solutions was also informed over another competitor that has developed a system very similar to the AutoBatch™. Agrotop Spray Technology, located in Germany, won an innovative award for the QuantoFill M multi proportioner at the Agri Technica show in 2011 (Agrotop, 2012). The only image found of the unit is shown in figure 9. Although N_2 Line Solutions did not become aware of this product until the conclusion of the project, no patents were discovered for the competitive product. In addition, few descriptions were found on the product. It appears that the system uses an electric pump to pull in up to five chemicals based on the desired chemical volume. The metering method or flow rate could not be determined based on the information available.

Figure 9. The QuantoFill M chemical proprtioner from Germany is the closest competition to the AutoBatch™.

Patent Review

Upon reviewing competitive products, N_2 Line Solutions found no companies producing products, competitive ideas, or patents relating to the proposed design of the automated batch chemical mixing system. With no competitive products on the market or patented ideas directly related to the design concept, the team determined it necessary to look at similar patented products and ideas in the agricultural industry to ensure a similar process has not already been patented. Most of the patents found related to fluid delivery pressure on a sprayer boom, direct chemical injection at the boom nozzles, or modules used for fluid delivery shutoff such as sectional boom control. A detailed patent list of similar concepts is shown in the appendices.

Research and Development

After thoroughly researching competitive products and patents, N_2 Line Solutions confirmed that there is not a product on the market that features a fully automated, high volume, closed chemical injection system with a Clean in Place (CIP) feature. Acknowledging that there was little more to learn from competitive product analysis, the team turned to commercial applicators, farmers, extension agents, and faculty members for more information. In order to further develop the design criterion, the team first met with the end user of the product to address the concerns and expectations of an automated system with those that are most familiar with the process.

Concept Development

N_2 Line Solutions contacted numerous applicators for feedback regarding an automated chemical mixing and fast-fill system, and chemical shuttles in general. The team also traveled to Matt and Adam Steinert's farm near Covington, OK to look at their current system and visit with them about the requirements of an automated design. The Steinerts earned degrees from Oklahoma State in Biosystems Engineering and now farm and run a commercial application business. They spray thousands of acres annually and may handle twenty or more products daily. The Steinerts were updating their current system when the team visited them. The primary criterion that stemmed from the meeting was:

Figure 10. Matt Steinert is a commercial applicator that helped N_2 Line Solutions understand the application industry.

1) Protecting the system from corrosion due to moisture, chemicals, and physical damage.
2) Developing an automated volumetric system to visually check the system.
3) Including a pump on the platform instead of the sprayer's pump to achieve the load time.
4) Creating suction pressure to help dispense chemical faster and speed up cleanout.

Matt also suggested the team consider utilizing a hydraulic pump to allow for variable flow rates to be achieved with a controller and interface. For instance, this would allow a user to treat the base water solution with ammonium sulfate at a slow rate initially while the chemical batch is entered into the system and help prevent the sprayer form being filled with solution prior to all the chemicals being added. Additionally, some chemicals may need to be slurried in the inductor and would therefore take more time to mix than other tank batches. In addition to controlling the flowrate of the solution being loaded onto the sprayer, Matt also expressed concern with the measurement system for the chemicals. Matt stated that his electronic flowmeters are replaced about every 20 months. This is due to worn seals, material degradation, and calibration inaccuracy due to high viscosity fluids building up in the flow meters. He also explained that he has pulled some of the electrical components off of his system in recent years and gone back to a more manual process for reliability reasons. “This is a great idea and I’m all for it, but it has to work every time, all the time. You have nothing without reliability,” Matt warned.

Figure 11. Visiting a producer to learn about the industry.

Providing a functional and reliable product means providing a system that continually meters and delivers the requested amount of product. This is the utmost concern for N_2 Line Solutions. Although potential customers have made it clear that flowmeters wear out and electrical systems don’t typically last well outdoors, N_2 Line Solutions is required to use “off-the-shelf” components that are regularly available to develop a fully automated system, as requested by Microfirm. Acknowledging this, the design team ruled out the volumetric measurement system and elected to use flowmeters to measure chemical. According to Raven, flowmeters can provide 1-2% accuracy for most agricultural chemicals if installed properly. N_2 Line Solutions can accept a shorter life span on “off-the-shelf” components as customers will be able to easily attain replacements. Furthermore, the design team will emphasize contained, robust electrical components for the automation components of the chemical mixing system. Selecting durable components and enclosing them where possible will help to reduce physical contact, aid in preventing exposure from chemical spills, and assist in preserving the components as they will be secluded from the elements.

N_2 Line Solutions has found no supporting evidence that another manufacturer produces a fast and reliable on-board sprayer pump with the exception of John Deere’s LoadCommand system that is a specific option. Most sprayers only feature a small pump such as the one shown in Figure 12. After meeting with one of the largest chemical applicators in the area, N_2 Line Solutions confirmed this research. Matt advised that a pump within the system would be necessary to achieve the time requirements of the project. He also allowed that his system utilizes a primary pump and the pump on the sprayer to fill the spray rig quicker. The team determined it would pursue the idea of an on-platform motor and solution pump once the Steinert meeting commenced. Due to market acceptance of an automated fast-fill mixing platform, N_2 Line Solutions will provide a preliminary model with its own power unit. Not only will this help transition the market as sprayer pumps continue to grow larger, but it will also allow the system to be utilized on all makes of sprayers across the world. In addition to the Steinerts, the team also visited and completed phone interviews with commercial applicators and producers regarding the needs and level of importance for an injection shuttle. That information is summarized in Table 6.

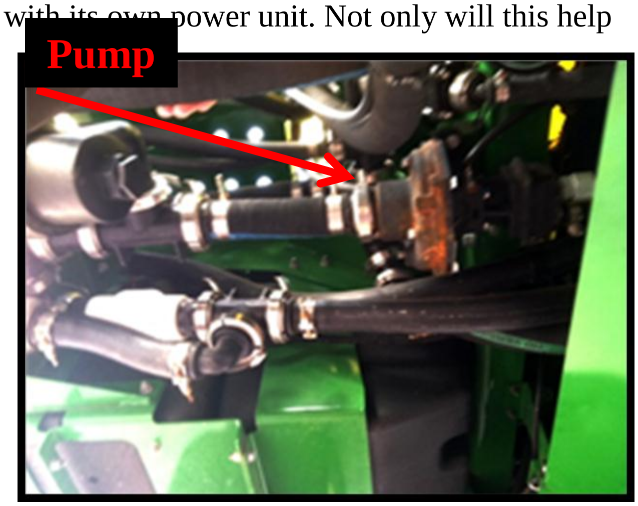


Figure 12. Small standard sprayer pumps produce low flow rates.

Table 6. Interviewed target customer feature importance breakdown.

Customer Functionality Breakdwon by Importance Level for a Chemical Injection System					
Feature	Mandatory	Very Important	Important	Nice to Have	Individual Preference
Maintained or Improved Chemical Accuracy	✓				
Reliable System with No Down Time	✓				
Reduced Batch Loading Time		✓			
Affordable		✓			
Robust and Durable System		✓			
Effective Cleanout Cycle		✓			
Reduced Chemical Exposure and Spillage			✓		
Batch Load Documentation			✓		
Simple to Operate			✓		
Clean In Place				✓	
Total Batch Volume Monitoring				✓	
Compact & Mobile System				✓	
Automated System					✓

All applicators agreed that the most important aspect of a chemical shuttle, particularly an automated one, is the ability to meter the injected chemicals accurately every batch. The next mandatory function was system rigidity and reliability. Although each producer said they wanted a system that did not have electrical problems, many acknowledged that parts do fail and that the components should be easily attained in the event that a part failed. Other important features included shorter re-fill time, an affordable system, and a productive cleanout mechanism. Most applicators are aware of the dangers associated with chemical exposure and take the necessary precautions but many admitted that a closed transfer system would be very lucrative. All applicators questioned suggested that the interface or control method be simple to operate. Of those polled, some also allowed that improved record keeping would be a value added product. Many applicators were concerned with an automated system because of the chance for an inaccurate batch load due to a failed component that was not caught in time. They also expressed that the environment and corrosive chemicals would make it tough to keep electronics from deteriorating.

Chemical Selection

N_2 Line Solutions formulated a list of chemicals to consider for the component selection and software development of the fast-fill mixing system. Since Microfirm wanted to focus on the Midwest region with an initial emphasis on wheat production, the team compiled a list of chemicals most commonly used by wheat producers in Texas, Oklahoma and Kansas. Dr. Joe Armstrong, Plant and Soil Sciences professor at Oklahoma State, and Dr. Curtis Thompson, professor of Agronomy at Kansas State provided feedback and helped N_2 Line Solutions develop the following list of herbicides, additives, and surfactants (OCES, 2012). This chemical list will help the design team calibrate metering instruments and determine batch sizes and loading constraints based on application rates.

1) ***2,4-D Amine***
2) ***MCPA***
3) **Axial XL**
4) **Clarity (soluble)**
5) **Finesse (dry)**
6) **Olympus (dry)**
7) **Ammonium Sulfate (liquid)**
8) **Ammonium Sulfate (dry)**
9) **ChemSurf or Squire (NIS)**
10) **Glyphosate**
11) **Dicamba**
12) **Paraquat**
13) **Valor**
14) **Brash/Weedmaster**
    a. **2,4-D Amine + Dicamba**
15) **Gramoxone**

Phenoxy chemicals leave behind high residuals and can cause commercial applicators lots of problems if the chemical resin is left behind when switching to a different tank batch and/or crop

(NZIC, 2012). The chemical resin can significantly hurt the crop's yield potential or even kill some crops entirely. N_2 Line Solutions discussed phenoxy chemicals with the Steinerts, as well as area agronomists and producers. The consensus was that no producer or applicator would want to incorporate phenoxy chemicals into a fast-fill, automated system due to increased liability. For instance, the Steinerts utilize a specific applicator for just phenoxy chemicals due to the risk of contamination.

The team presented the chemical list and information to Microfirm. The sponsors concluded that phenoxy chemical cleanout is a problem in itself, and the team should not focus on phenoxy chemicals and their cleanout within the system. An applicator would likely have to utilize a solvent very thoroughly within the system to eradicate any residual. In addition to developing a list of chemicals, N_2 Line Solutions also formulated application rates and batch volume requirements for each chemical based on the average and maximum rates stated on the label or suggested by agronomists. The following spreadsheet itemizes each chemical's average and maximum application rates in order to estimate the total volume required for potential tank mixes (OSUPSS, 2012). In addition, the total volume required for various batches will provide an indication of how fast the chemical must be injected in order to meet the time constraints.

Table 7. Maximum and average application rates for selected chemicals (Armstrong, 2011).

Product	Max. Rate	Ave. Rate	Units	Max. Rate (Gal/Acre)	Ave. Rate (Gal/Acre)
Glyphosate	64	32	*fluid oz./Ac.*	0.50	0.25
Ammonium Sulfate (liquid)* **	5	4	*gal/100gal*	0.50	0.40
2,4-D Amine (phenoxy)	2	1	*Quarts/Ac*	0.50	0.25
Brash/Weedmaster -> 2,4-D Amine + Dicamba	3.33	2	*pints/Ac*	0.42	0.25
Gramoxone	3	1	*pints/Ac*	0.38	0.13
Ignite--cotton rotations	40	30	*fluid oz./Ac.*	0.31	0.23
MCPA (phenoxy)	2.5	1.5	*Liters/Ha*	0.27	0.16
Paraquat {Also Gramoxone}	2.4	1.5	*Liters/Ha*	0.26	0.16
Axial XL	16.4	16.4	*fluid oz./Ac.*	0.13	0.13
ChemSurf or Squire (Non-Ionic Surfactant)	6	2	*pints/100gal*	0.08	0.03
Dicamba	0.6	0.3	*Liters/Ha*	0.06	0.03
Clarity (soluble) {Also Dicamba}	8	5	*fluid oz./Ac.*	0.06	0.04
Valor	6	2	*fluid oz./Ac.*	0.05	0.02
Harmony Extra	1	0.6	*fluid oz./Ac.*	0.01	0.00
Finesse (dry)	0.5	0.2	*dry oz./Ac.*	--	--
Olympus (dry)	3.5	2	*dry oz./Ac.*	--	--
Ammonium Sulfate (dry)	17	10	*lbs/100gal*	--	--

Component Analysis

Microfirm presented N_2 Line Solutions with some component criterion to meet. Two of the most important were:

1) Selecting easily accessible, “off-the-shelf” components that are readily available.
2) Utilizing a programmable logic controller to automate and control the system.

N_2 Line Solutions used these parameters to channel component research. The team divided the component research into four areas: power unit, metering, chemical injection, and valves and fittings. Since components must be “off-the-shelf” or be readily available to customers, the team focused on chemical equipment, sprayers, and agricultural equipment dealers for specs and pricing.

Power Unit

N_2 Line Solutions considered several alternative pump types including positive displacement pumps, direct injection pumps, and centrifugal pumps. The team additionally compared electrical and gas engine power supplies. After researching positive displacement pumps and direct injection pumps used in chemigation, the team discovered neither would be applicable for the project due to the limited flow rates produced. It was projected that 250 gallons per minute would be a minimum flow rate for the primary pump in order to transfer 1200 gallons in under five minutes. However, the team also determined that a lower flow rate would be desired while loading chemical to prevent the sprayer from being filled prior to the chemical addition. That would demand more pump capacity to finish filling the sprayer within the desired time frame once the chemical has been injected. The team determined a centrifugal pump to be a good option as it is durable, capable of handling chemicals, mobile, and it can exceed 400 gallons per minute of flow. Having selected the pump, the team next considered the power unit to drive the pump. The first combination the team analyzed was a hydraulically driven centrifugal pump with an electrical power supply. This system was lucrative to the team for these reasons:

1) Operation can be managed from the user interface after starting the generator. The electrical motor's speed will be constant and the user can make all pump speed adjustments hydraulically from the interface/controller.

2) The hydraulic motors can be adjusted to control the water or fertilizer solution, or the chemical product flow rate using the swoop valves from the controller.

3) This flow rate control eliminates the need for a primary system flow regulating valve and the team feels it will assist in providing a higher level of metering accuracy consistently.

4) This system will allow the user to turn off the secondary pump from the interface when not in use. Otherwise, the pump would often be left running between chemical addition and system cleanout.

After the design analysis was completed on hydraulic pumps, the team analyzed the costs associated with the hydraulic option. To determine if the system would provide a viable and affordable option for the automated mixing station, the team compared the cost to power unit costs of mechanical systems. The hydraulic system offers many features that would allow the team to provide the operator accessibility from the interface, but it comes at a price. An estimated system budget for the major components is shown in the following Table.

Table 8. Hydraulic system cost estimate.

Cost Projection for Hydraulic Power System		
Component	**Specifications**	**Estimated Cost**
Primary Centrifugal Pump	3" In/Out with 350 gpm	$ 800
Secondary Centrifugal Pump	2" In/Out with 75 gpm	$ 600
Primary Hydraulic Motor	8 gpm, 3600 rpm	$ 500
Secondary Hydraulic Motor	8 gpm, 3600 rpm	$ 750
Hydraulic Pump	2000 psi, 20 gpm	$ 1,300
Swoop Valves	8 gpm each	$ 1,100
Electrical Power Source	23 hp	$ 2,000
Gas Generator	17,135 Watts	$ 3,000
Hydraulic Hoses/Fittings	8 foot and 10 couplers	$ 150
Total Hydraulic Components Needed to Purchase:		**$ 10,200**

The team concluded that the hydraulic option would not present enough benefits to justify the added cost to the product. An automated system will be more expensive due to the electronics and adding an expensive power unit that many producers do not already use will hurt the marketability of the product. Next, the team considered small gasoline engines to power the centrifugal pump. There are few 2" pumps that exceed 250 gallons per minute, but nearly all 3" pumps provide the flow rate capability that is needed. Two of the most common pump brands in the agricultural industry are Banjo and John Blue pumps. Although the team elected to pursue a gas engine driven three inch centrifugal pump based on the design criteria; the team also recognized that the industry primarily uses this same pump configuration currently. The 13hp Honda motor and 360gpm Banjo pump shown in Figure 13 is available through Schaben Industries for $1800.

Figure 13. Three inch Banjo centrifugal pump with 13hp Honda engine.

In addition to the primary pump used to transfer the mixed solution to the sprayer, the team also considered secondary pumps to pull chemical into the system from the containers. However, the team determined that this was an ineffective, expensive, and unnecessary method of drawing the chemical.

Chemical Injection

The method of chemical injection influences the metering accuracy and the cleanout time and effectiveness. Once the design team narrowed the system alternatives; two options rose to the top. The first was a secondary gasoline engine and centrifugal pump similar to the main power unit to help pull chemical out the chemical loop and to speed up the cleanout process. This option added $1200 to the cost of the system and would not generate enough suction pressure to complete the chemical draw desired for the system. The next alternative was a venturi that creates a pressure differential by throttling the carrier solution through an orifice to create suction that draws the chemical from the secondary system as shown in Figure 14. The maximum vacuum created by a venturi for agricultural applications draws chemical at a maximum of 55 gallons per minute. While the venturi provides a way to increase the flow rate of the chemicals being metered and added to the batch, it also provides a quicker way to flush the chemical residue left in the system once the chemical has been metered and mostly injected. However, the team had previously ruled out the venturi method due to the decrease in carrier solution throughput. Further research revealed that a venturi bypass would alleviate this problem so the design team elected to use a venturi system in place of a secondary chemical pump.

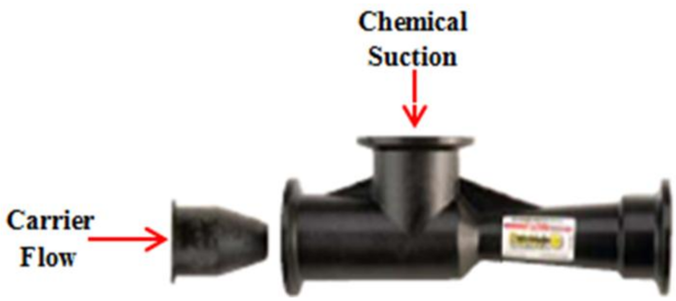


Figure 14. Conceptual throughput view of venturi.

The disadvantage of a venturi is that it restricts the flow of the carrier solution. In order to avoid decreased flow rate of the carrier solution, N_2 Line Solutions considered adding a carrier solution bypass to the system. As shown in the Figure below, this would allow the carrier to flow through the orifice of the venturi and draw suction on the chemical port while still allowing excess flow to detour from the venturi and continue filling the sprayer at a high rate. The amount of bypass can be governed by a manual valve to slow the flow rate or provide maximum suction to the chemical port if utilizing an inductor to draw in chemicals that were manually slurried.

Figure 15. Bypass to increase throughput of carrier solution.

Metering

N_2 Line Solutions researched four types of flowmeters: mechanical, pressure based, mass flow, and magnetic.

Mechanical Flow Meters such as turbine flow meters are the most common type of metering device currently used by applicators. This flowmeter utilizes the axial revolving of a propeller to determine the flow of a fluid through it. Although it is reliable when used for the same material application over and over, small accuracy variations can be presented when fluids of different densities are used.

Pressure based meters, like venturi meters, restrict the flow of a fluid and use pressure sensors to measure the differential pressure that flows across it. This differential has preset values programmed into the system that allow the meter to display the flow rate of the fluid. Pitot tubes utilize Bernoulli's equation to calculate dynamic pressure and fluid velocity. These flowmeters are commonly used to measure wind speed for airplanes and high velocity fluids.

Mass flow meters work on the principle of inertial flow in order to gauge mass flow rate of a fluid. These types of sensors are not used as commonly as the mechanical and pressure meters, but they do offer an additional benefit over the other types of meters. Mass Flow Meters have a greater flexibility of fluids capable of measurement. This type of meter may need to be tested further in the application of a chemical batch system to see if it can reduce the error associated with measuring various fluids with fluctuating densities and viscosities.

Finally, magnetic flowmeters offer great flexibility in the range of liquids measured. Typically, this type of meter is used in wastewater or dirty liquid applications. The function of magnetic meters is based on Faraday's Law where the fluid being measured is electrically conductive. In addition, this type of meter requires less straight pipe upstream than a turbine meter which could potentially reduce the special scale of the overall system. Furthermore, magnetic flowmeters do not measure air; therefore these meters provide more accurate results when air bubbles are present in a liquid. Additionally, magnetic flowmeters are typically self-contained, but they do have the capability to be hard wired into a plc for monitoring. These meters are more expensive than the same size of turbine meters, but the measurement range is greater with the magnetic meters. This increased range may allow a smaller diameter magnetic meter to be used. For instance, a 1" electro-magnetic meter has the same range of metering that a 2" turbine meter has and the 1" meter is more affordable.

Per client request, the team ruled out volumetric tank monitoring for chemical injection. It was determined that the most robust and accurate way to monitor the volume of the chemicals added to each batch load was utilizing flowmeters. Flowmeters allow chemicals to be measured completely hands-free whereas volumetric systems often require manually valves to be operated. Based on availablity and pricing; N_2 Line Solutions determined that Raven mechanical turbine flowmeters were the best option for use in the conceptual system. These metering devices are proven in the agricultural industry and are constructed to meter the chemicals associated with agricultural applications. The flowmeters create pulses as the turbine rotates and generates a signal each time it passes by the magnetic sensor. Each new unit comes with a calibration number that correlates the number of pulses per gallon. These meters can be recalibrated relatively easily as well. These turbine flowmeters provide a viable option for this application, but the client should be prepared to recalibrate or replace the meter approximately every two years depending on usage.

Figure 16. Two inch, M100 220 flanged Raven flowmeter.

Valves and Plumbing

N_2 Line Solutions researched electric valves with quick response times for use in the fast-fill station. In order to inject chemical accurately, the shutoff valves must function quickly in order to stop flow once the flowmeter has read the desired value, particularly at low chemical volumes with high injection flow rates. First, the team investigated agricultural and chemical applicator products and concluded that the industry primarily utilizes polyethylene ball valves. Next, the team looked at other types of ball valves and other vendors outside of agricultural chemical suppliers. N_2 Line Solutions found most other suppliers, especially in the oil and gas industry, use more robust valves with quicker response times, larger sizes, and flow capabilities above what the chemical injection system requires. Utilizing components with qualities above the required capabilities adds unnecessary cost so the team elected to utilize polyethylene valves that are readily available and currently used by applicators. The team contacted Schaben Industries and reviewed Banjo's catalog for specifications and prices. Few valve restrictions were found outside of response time. The fastest ball valve cycle time for a two inch valve is one and a quarter seconds while the cheaper valve closes in just four seconds. Since the team had access to two inch Banjo valves through the Biosystems Department, the team choose to select Banjo products for valve components for testing and prototype construction.

N_2 Line Solutions also researched and designed several ways to clean out the chemical residue in the system once the product has been metered and delivered to the sprayer. Cleanout is very important as chemical residuals can be a toxic ingredient in the next batch load. The team considered using a three way ball valve to flush water back through the chemical loop, but feared it would slow the fill time down by restricting flow to the sprayer. In addition, the following line diagram design shows that the cleanout would also be using solution that is already contaminated with chemical and therefore takes longer to flush the system clean. A legend is included to denote the components for the line diagrams shown throughout the following sections.

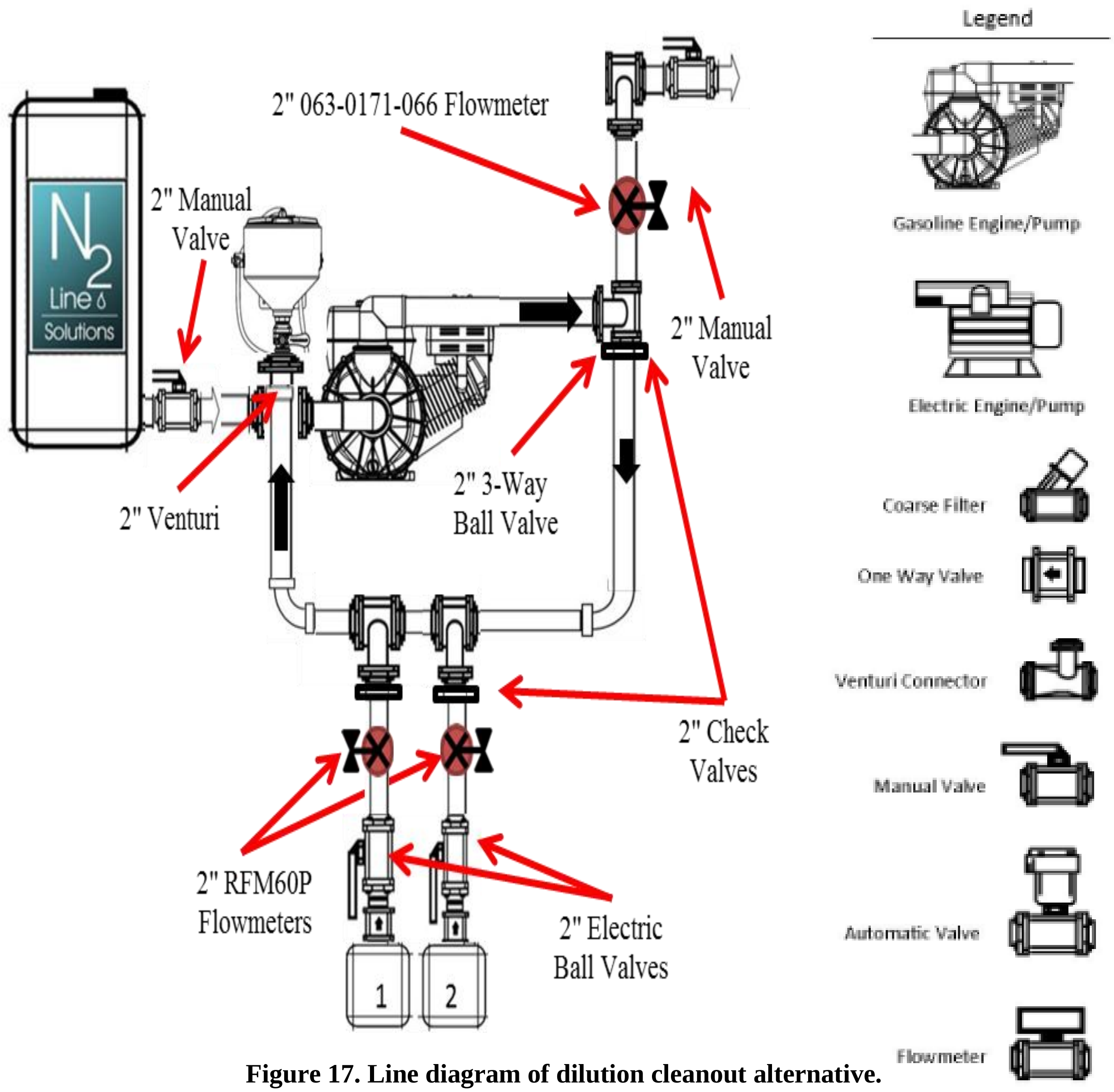


Figure 17. Line diagram of dilution cleanout alternative.

The team continued to work through designs to devise the most effective Clean in Place (CIP) system. An alternative discussed was allowing air to be pulled into the chemical loop to help pull chemical out using the venturi once it has been metered. However, this idea proved ineffective as the slightest amount of air in the system caused the primary pump to lose its prime. Next, the team installed a solenoid valve to circulate fresh water into the chemical sub system after the chemical has been metered. The team used Viton Remcor 2100b solenoid valves on hand that are available through Raven or Schaben Industries. This is a 2.4amp, 12 volt valve with a 10gpm max flow rate.

Electrical Hardware and Software

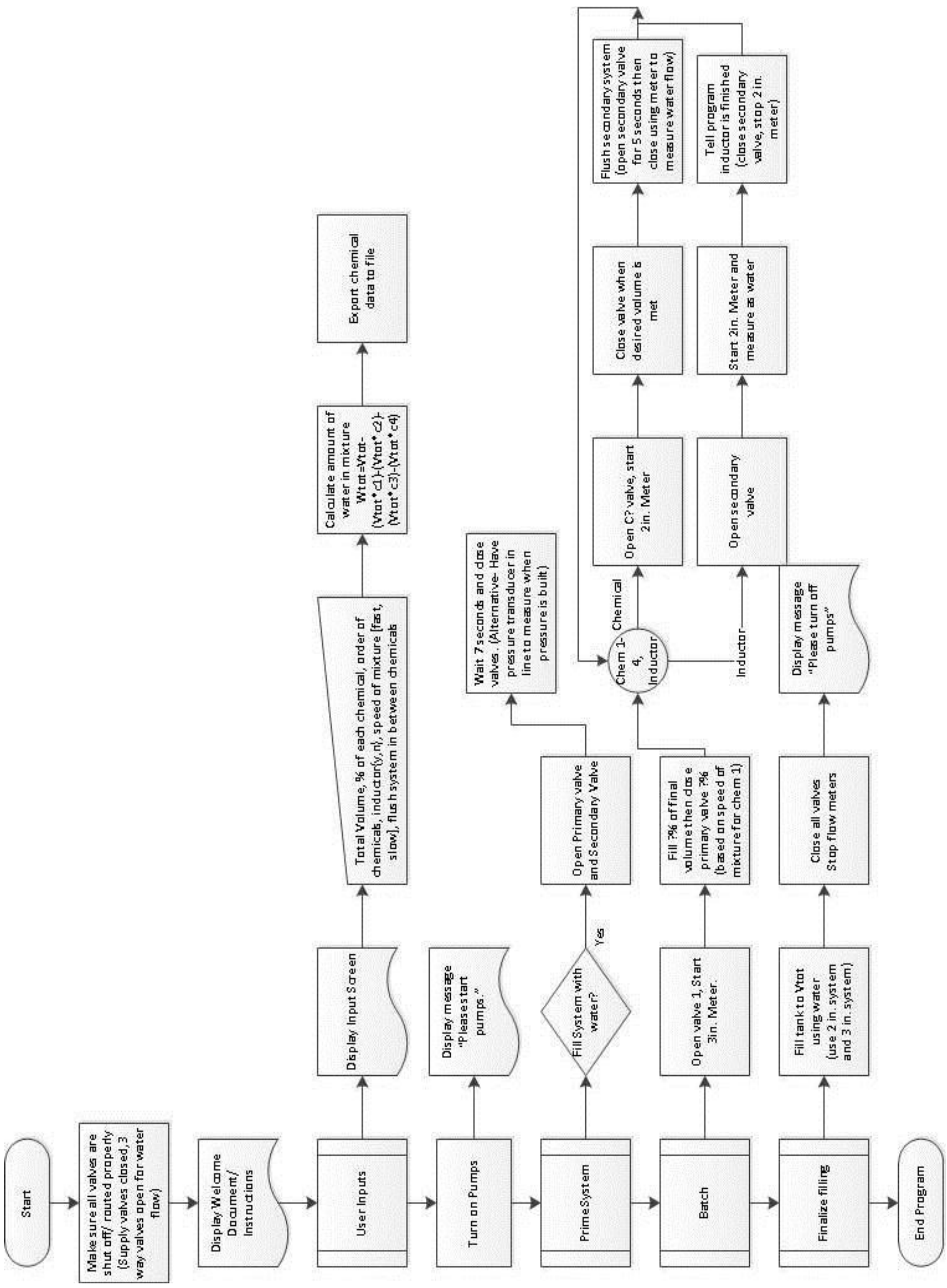
In order to complete the project, the team will borrow a programmable logic controller (plc) from Dr. Wang, Biosystems professor. This type of controller is being used in order to accommodate the client. The team also considering using an Arduino but discovered it would be less favorable to monitor the components (Arduino, 2012).The plc available for use is an Allen-Bradley 1762-L24BWA with one high speed counter. In order to read the flowmeters, the team constructed an amplification circuit consisting of three op-amps (LM741CN) to raise the signal from 8 volts to 14-20 volts. The circuit was constructed using a CNC prototype and 15 and 12 kΩ resistors were used. An optional 12 to 5 volt power converter was added to accommodate a pressure transducer. Six relays were required for the system. The Finder 93.01.7.024 sockets contain Finder 34.51.7.012.0010 relays that have a 12 volt, 6 amp trigger.

Figure 18. Allen-Bradley 1762-L24BWA programmable logic controller for algorithm development.

The software consists of ladder diagrams and was developed on a starter edition of RSLogix 500 (PLC Trainer, 2011). The license required renewal and a 3.5" floppy disc contains the software license to activate the program. In addition to a floppy disc, the plc also requires an RS232 port for serial communication. Due to these requirements, an older Dell laptop was provided for duration of the project by Dr. Weckler. Additionally, Duestch connectors were used to construct custom wiring harnesses to connect components to the plc for the prototype.

Design Criterion

After researching competitive products, visiting with applicators, inspecting manual systems, and analyzing components, N_2 Line Solutions began formulating the process required to fill a sprayer as outlined in the following preliminary flowchart.


Start
Make sure all valves are shut off/ routed properly (Supply valves closed, 3 way valves open for water flow)
Display Welcome Document/ Instructions
User Inputs
Display Input Screen
Total Volume, % of each chemical, order of chemicals, inductor(y,n), speed of mixture (fast, slow), flush system in between chemicals
Calculate amount of water in mixture Wtot=Vtot-(Vtot*c1)-(Vtot*c2)-(Vtot*c3)-(Vtot*c4)
Export chemical data to file
Turn on Pumps
Display message "Please start pumps."
Prime System
Fill System with water?
Yes
Open Primary valve and Secondary Valve
Wait 7 seconds and close valves. (Alternative- Have pressure transducer in line to measure when pressure is built)
Batch
Open valve 1, Start 3in. Meter.
Fill ?% of final volume then close primary valve ?% (based on speed of mixture for chem 1)
Chem 1-4, Inductor
Chemical
Open C? valve, start 2in. Meter
Close valve when desired volume is met
Flush secondary system (open secondary valve for 5 seconds then close using meter to measure water flow)
Inductor
Open secondary valve
Start 2in. Meter and measure as water
Tell program inductor is finished (close secondary valve, stop 2 in. meter)
Finalize filling
Fill tank to Vtot using water (use 2 in. system and 3 in. system)
Close all valves Stop flow meters
Display message "Please turn off pumps"
End Program

As delineated in the component analysis section, the fast fill station will consist of the following major components:

1) Primary gasoline engine and centrifugal pump unit to propel the carrier solution.
2) Metering system for each chemical and the total batch size.
3) Injection mechanism to impel chemicals into the carrier solution.
4) Electric valves to contain fluid, prime the system, and control flow.

The team designed several options for the batch mixing station to review and test. Many of the design questions related to metering accuracy as well as chemical injection and the time required to run a batch.

Preliminary Design Options

The first design is shown in Figure 19 and consists of four three-way valves. The team wanted to create an iterated manifold for chemical injection using the three-way valves available. This alternative utilizes a secondary pump to increase the pressure in the secondary system in order to overcome the pressure differential at the injection site. It provides a cleanout loop when all chemical is in the off position and carrier solution can be used to push the chemical out of the loop. Although the method is feasible, the team determined that the method to measure the chemical would not be effective as the loop contains too much volume and prohibits flow so the system would still have chemical in it while the carrier solution cleans it out. The meter would not be able to determine when the chemical is replaced by carrier solution so this design was ruled out.

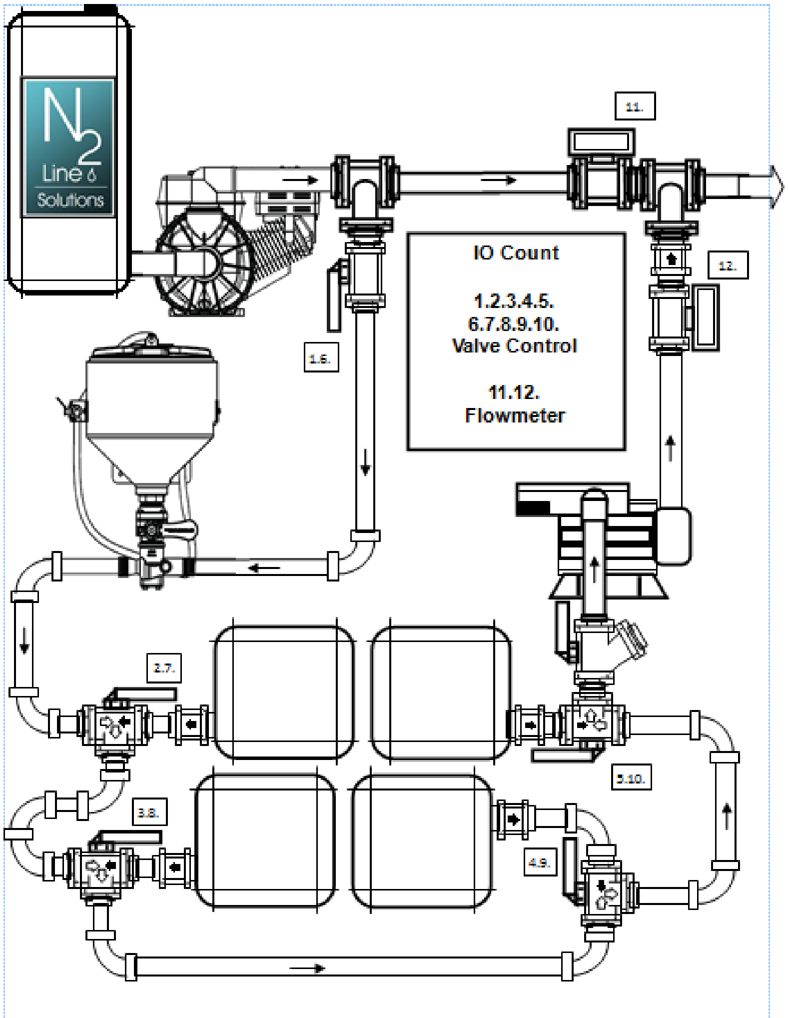


Figure 19. Original design concept developed by N_2 Line Solutions.

The next design alternative that was investigated consisted of the same concepts as the first with an improved injection site and an updated metering system. This alternative was reviewed with and without a secondary pump. The design features one primary flowmeter on the main line that measures the carrier solution traveling to the sprayer and two chemical meters on the chemical loop. The first meter lies downstream of the chemical manifold valve site and measures the chemical volume. The design requires the IBC totes to be elevated in order minimize the unmeasured volume left in the chemical loop. The second chemical meter lies before the chemical manifold and measures the washout solution that passes through the chemical loop. The team determined that the software must account for the chemical volume based on the first meter and also record the cleanout fluid based on the second metering device while still accounting for it a second time as it passes the second meter. The system would use the differential between the two chemical meters to determine how much extra chemical was left in the system when it was cleaned out. This design presented some accuracy issues as well as problems injecting the chemical in the primary solution. The operating pressure at the injection site was calculated to be around 40 psi on average. This would require the IBC containers to be highly elevated in order to provide the head pressure to inject the chemicals. This presented issues when considering space limitations and chemical totes that are nearly empty. The design alternative is shown below with and without a secondary pump option.

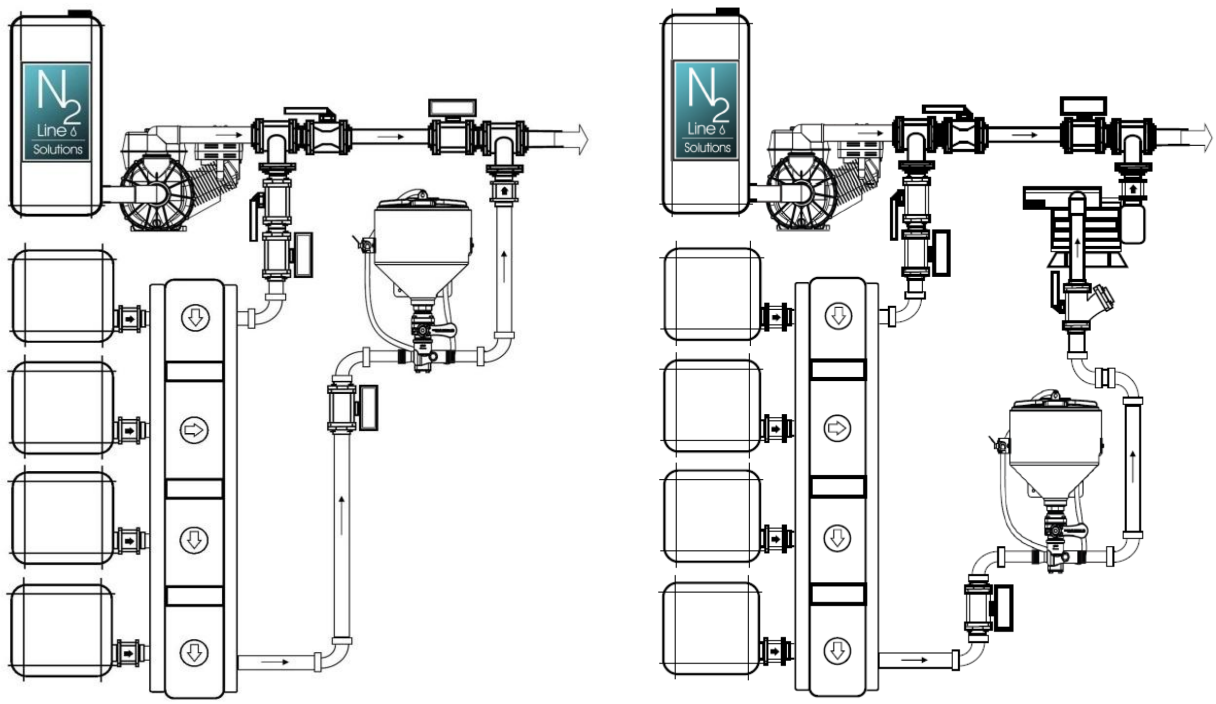


Figure 20. The second alternative presented metering accuracy problems.

After further research, the team composed a third design alternative as shown in Figure 22 that consisted of two major changes. First, the team added chemical monitoring flowmeters to each IBC to decrease the potential volume left unmeasured before cleanout and to allow multiple chemicals to be metered and dispersed simultaneously. Next, the team re-investigated a venturi option that had previously been ruled out due to throughput limitations and low injection flow rates. The team determined that a venturi could potentially provide up to 45 gallons per minute of fluid injection with unknown throughput; however, testing could reveal that a venturi bypass would maintain the benefits of the system while still allowing carrier solution to load the sprayer at the desired maximum rates. A three way valve was added to the system as shown in Figure 21 to temporarily close the valve to the middle position to allow flow to clean out the chemical loop while still allowing the sprayer to be filled at a lower flow rate. However, the team did not like reducing the fill rate in order to accommodate the clean out cycle. The design also utilizes solution already containing chemicals to flush out and dilute the system, so the team revisited the design process.

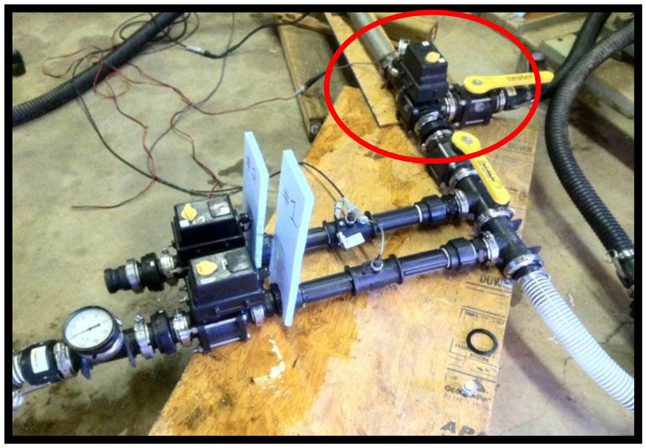


Figure 21. Original prototype cleanout design.

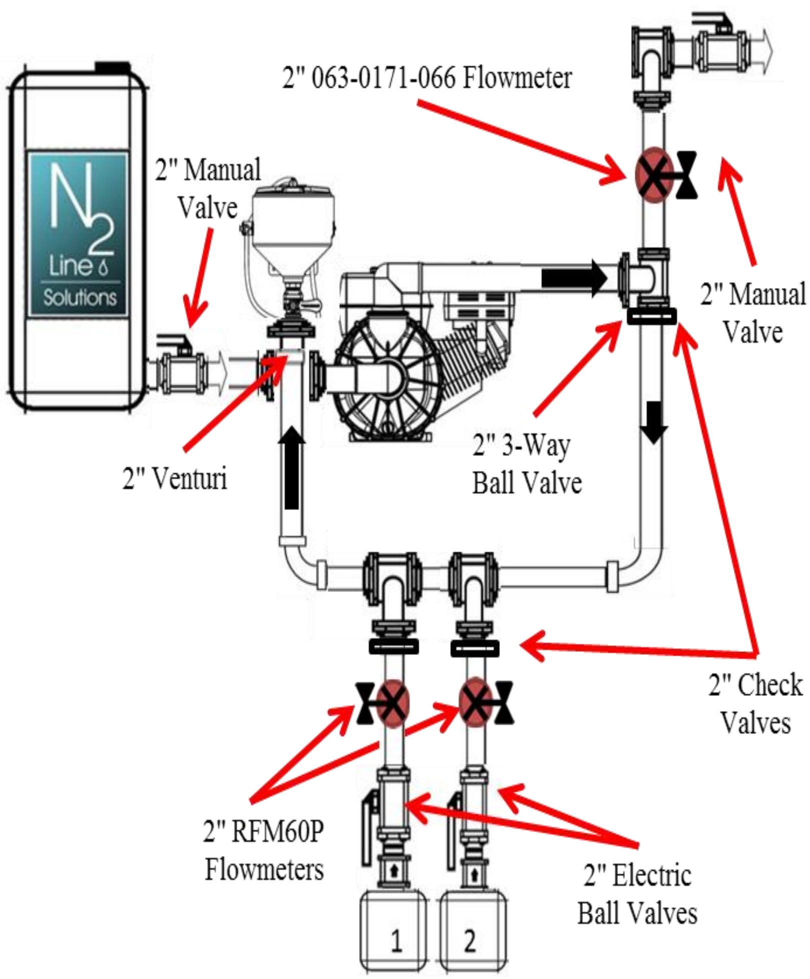


Figure 22. A third design option was utilized for prototype initialization.

Conceptual Testing

After producing the first three design concepts, the team acknowledged that there were many unanswered questions that could only be resolved with tests. The team began to build a mock system to be used for various test stands to verify component performance and measure results. The primary areas of concern for testing include:

1) Fluid Mechanics
2) Flowmeter Calibration and Accuracy
3) Flow Conditioning and Piping Geometry
4) Valve Response and Timing
5) Venturi Flow and Suction
6) Cleanout Functionality

Electrical Configuration

The first stage in the testing phase was compiling the electrical components and learning the software and controller used for the project. None of the N_2 Line Solutions staff was familiar with the controller, software, or programming language associated with this project and overcame a tremendous learning curve to become knowledgeable and capable of developing the algorithm on the platform used. The software for the plc was developed using ladder diagrams on RSLogix starter software. The team invested many hours learning about the new controller and the programming language. The starter version of the software does not contain some of the features and counters available on the upgraded version and this presented many problems that required the team to formulate a way to work around the software limitations to complete the necessary task.

Figure 23. Setting up the software and measuring the component output signals.

In some instances, the team was forced to seek help from the client to work through some of the software barriers. The team worked to rewire old hardware, amplify component signals, and to construct high speed counters to monitor the high volume of data within the program. Although many hindering programming issues were worked out, faulty, used hardware and components were to blame for some of the problems such as those associated with the think session in Figure 24. The team reviewed schematics and contacted Raven professionals to determine the factory specifications for repairing components (Raven Industries, 2005).

Figure 24. Diagnosing hardware issues.

The following Figure displays a piece of code that translates pulses from the flowmeter into gallons for the chemical volume injected from the first product tote.

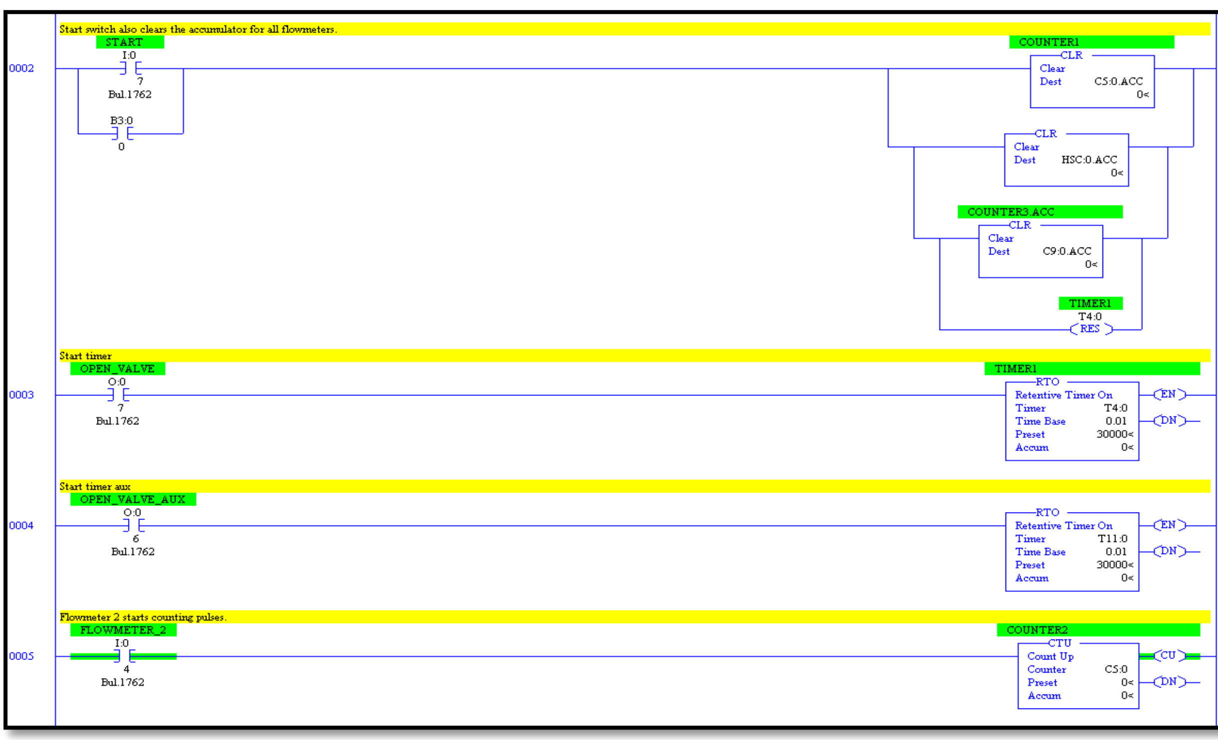


Figure 25. Example software language for the automation of the mixing station.

In order to complete the requirements of the project and run batch loads at the touch of a button for validation, the team derived a Human Machine Interface (HMI) for use on the laptop computer. This HMI was developed by the team from a source code available on Sourceforge, called AdvancedHMIv3. It uses Visual Studio to show the graphical components with an underlying VBA code structure which integrates the RSLogix addresses with the interface. As shown in Figure 24 , the team developed the HMI while performing tests in order to ensure the display depicted the actual system for testing purposes. The HMI contains a start button to run the system through to completion, an over-ride top button, counters for volume monitoring, timers for duration data, and manual controls for components. In addition, the plc was wired to an electric motor and centrifugal pump and is controlled from within the HMI.

Figure 26. Constructing an HMI.

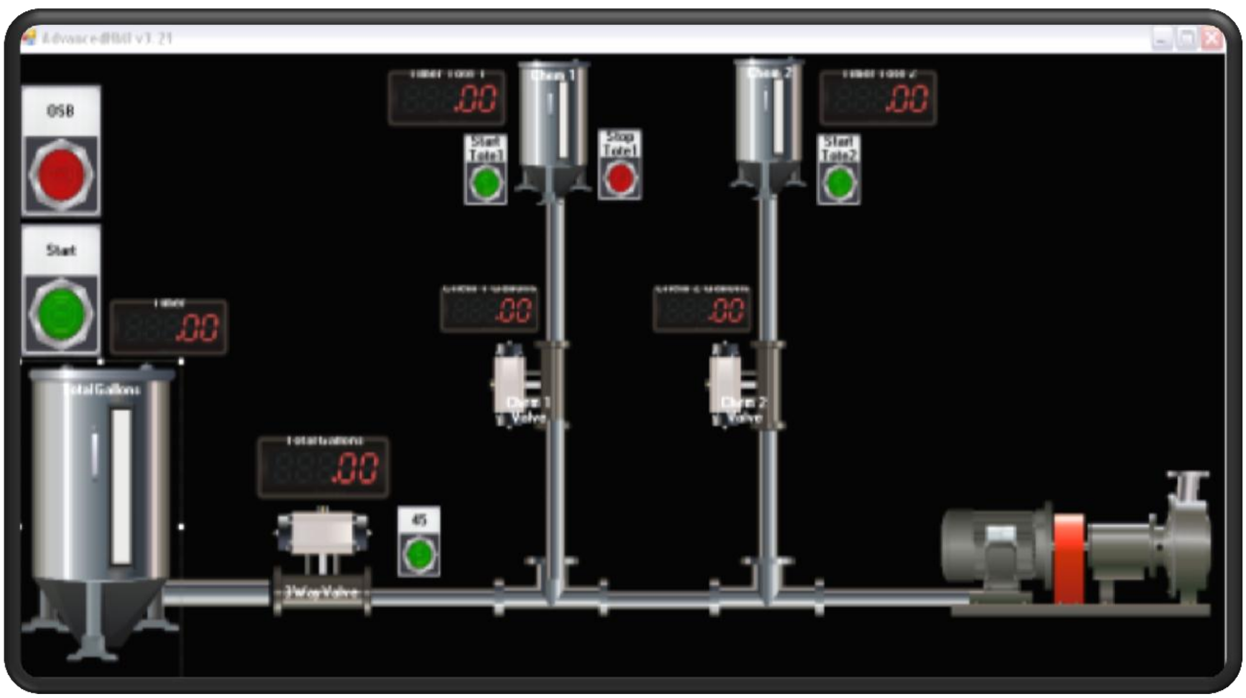


Figure 27. The HMI developed by the team for the prototype development.

Although the prototype development consisted of a HMI developed on a laptop computer, the team projects that an interface similar to the Divelbiss shown below will be used to conduct field tests of the batch mixing station. This type of unit would provide a simple and robust input panel to aid in the criterion development of the actual HMI. It would also help users acknowledge the viability and functionality of an HMI for this type of application (Divelbiss, 2012).

Figure 28. A potential development HMI with a robust housing and digital screen.

After the fast-fill chemical mixing station has been tested and proven, the HMI can be further developed and integrated into a Virtual Terminal (VT). Originally, N_2 Line Solutions had designed the potential VT layout for an automated injection system per request of Microfirm. The client later determined that further VT development was beyond the scope of the project. Microfirm and N_2 Line Solutions expect this type of automated injection system to be available on VTs in the operator’s station of sprayers in the near future. This convenience will allow users to select the desired chemical tote product, the needed chemical volume, total batch size, and request a system rinse from the comfort of the operator’s cab. This automation in combination will an automated tendering arm will make quick work of what was once a tedious task. A modern touchscreen version of the projected HMI is shown below.

Figure 29. Projected HMI of the final production design of the chemical mixing station.

Testing Results

Fluid Mechanics

The first analysis the team performed was general fluid mechanics to size the pump and pipe sizes in order to determine the valve and metering device sizes needed. An excel sheet was constructed to determine the total head provided by the pump. Bernoulli's equation, the head loss equation due to friction, and the equation for flowrate shown below were used to determine the pressure differences and head at various points throughout the fill cycle from the carrier tank to the sprayer.

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$$

$$h_L = \sum K\left(\frac{V^2}{2g}\right)$$

$$Q = A * V$$

The calculations provided a rough estimate of the system based on flow rate, pipe size, varying elevations, and pump capabilities. Although the pump creates suction on the inlet side, this analysis showed that it is only about 3-5 psi of vacuum which is not enough to pull chemical from the chemical loop. However, the discharge side of a two inch centrifugal pump with a 5.5 hp motor can supply 21 foot of head to fill a sprayer if needed based on a 200 gallon per minute flow rate. In addition, elevating the chemical IBCs allows the NPSH to be used to ensure chemical is drawn out of the totes. The following three basic concepts were realized from the fluid mechanics analysis:

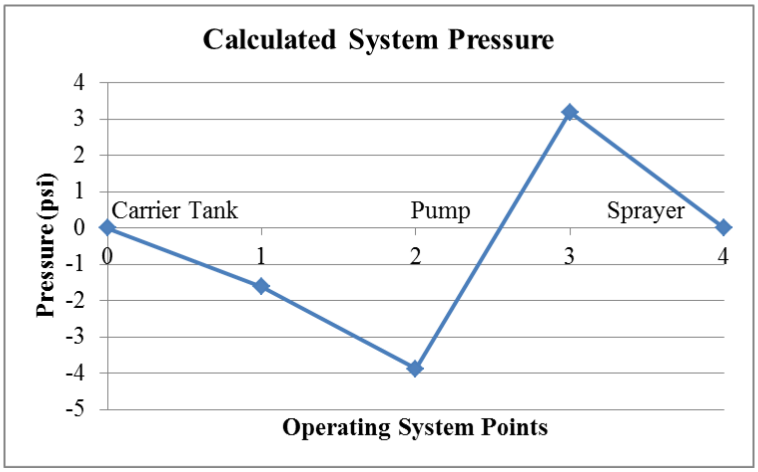


Figure 30. Head calculations for the system.

1) Horizontal distance is arbitrary.
2) Increased pump size increases head capability and flow rates to improve fill time.
3) The differential pressure across the pump is not large enough to draw chemical.

The team also investigated the effects of increased sprayer height or system head on total flow rate and metering accuracy. The team concluded that increased head resulted in decreased flow rates produced by the pump as expected, but the increased head did not influence the accuracy of the flowmeters.

Figure 31. Performing metering accuracy tests as a function of height of head.

Flow Conditioning and Piping Geometry

Although the system produces laminar flow throughout the operating station, the team considered utilizing a flow conditioning system to increase the accuracy of flowmeters if necessary. Turbine flowmeters operate best when presented with a uniform flow pattern. First, the team produced a test stand that created disturbance in the fluid flow and compared it to the results from the test stand with no flow disturbance. The metered volume was compared to the volume transported as determined by weight. The tests showed that the flow distortion scenario created no more than 0.44% error under various conditions. The team concluded that this could be attributed to the built in flow conditioning mechanism within the flowmeters and determined no further conditioning was needed.

Figure 32. Measuring flowmeter error with regarding to flow uniformity.

Further flow uniformity tests were conducted with valves to monitor the flowmeter performance while valves open and close. The Figure below depicts the test stand used to manipulate the scenario. The primary reason for the tests was to determine how many inches of straight pipe are needed upstream and downstream for best flowmeter accuracy. Three pipe lengths were considered: 6”, 12”, and 20” schedule 40 PVC pipe. The test results are summarized in Table 9 below.

Figure 33. Pipe length testing.

Table 9. Pipe length accuracy data and analysis.

Flowmeter Plumbing Accuracy		
Pipe Length	Average Percent Error 10Hz	Average Percent Error 20Hz
6"	0.21%	0.35%
12"	0.07%	0.05%
20"	0.44%	0.38%
Average Error	0.24%	0.26%

The percent error was measured for each length of pipe at two different pump speeds. The average percent error for each trial is indicated for each flow rate at each pipe length. In addition, the total volume error associated with the meter inaccuracy for a 50 gallon chemical injection is shown for 0.4, 0.25, and 0.1% errors associated with pipe length in table 10. At the maximum error (0.44%), the volume discrepancy for a 50 gallon metering event would be 28.2 ounces or about 0.22 gallons.

Table 10. Fifty gallon batch load total chemical error.

Potential Error in a 50 Gallon Chemical Load	
% Error	Error Per Batch (Oz)
0.4	25.6
0.25	16
0.1	6.4

The data concluded that the pipe length could be neglected and is likely attributed to the self-contained flowmeter flow conditioner. Although N_2 Line Solutions' data does not support the claim by manufacturers, the suggested pipe length before and after a flowmeter is 10mm times the inner diameter of the pipe used. In the case of these tests, the result for two inch pipe is 20mm or nearly eight inches. Raven documents that seven and one half inches should be used. Due to pipe nipple size availability, N_2 Line Solutions suggest that the client use six inch threaded nipples to connect flowmeters to the system in order to allow the fluid time to become more uniform after valves or other components. The following Figure is published by Raven and depicts the recommended pipe lengths and plumbing geometry that is most ideal for flowmeter use. Due to the debate in the industry and the discussions throughout the course of the project, this figure was included in this section of the report and not as an appendix to make it more visible.

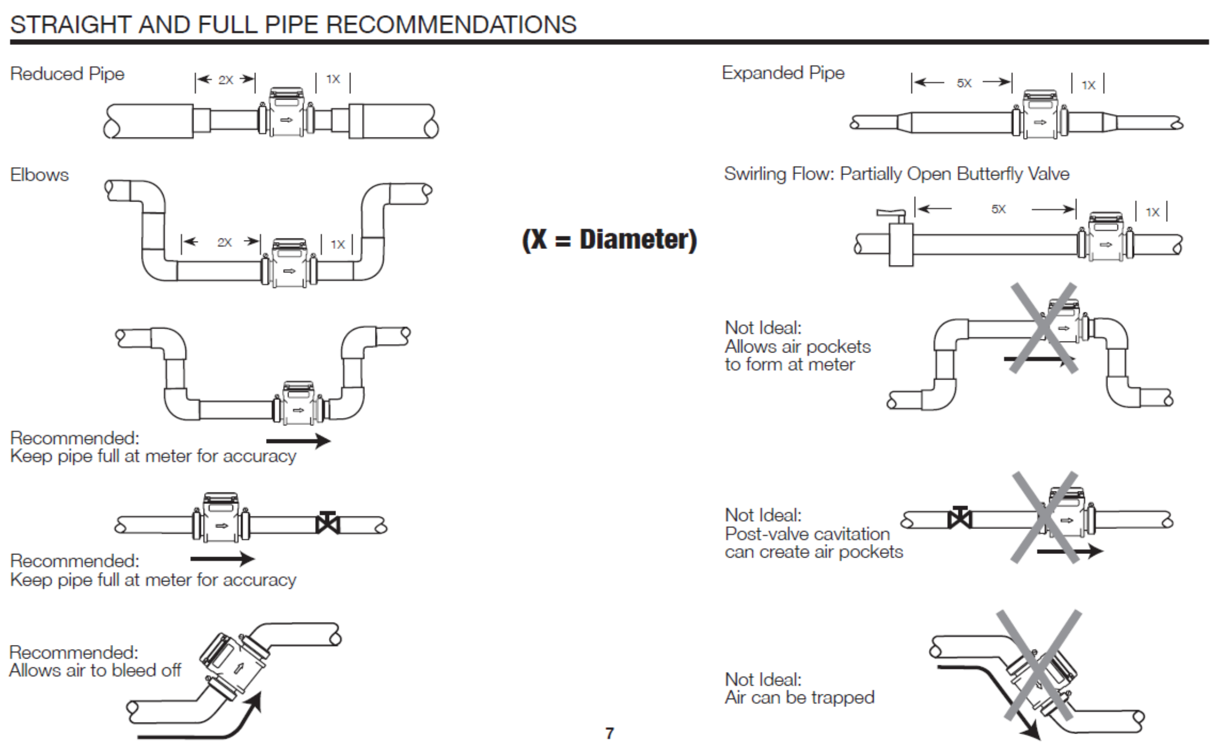


Figure 34. Manufacturer recommendations for Raven flowmeters.

Flowmeter Calibration and Accuracy

Dr. Marvin Stone presented the team with several Raven flowmeters to use for testing, experimentation, and/or the final prototype. He also provided the team with the following information and rules of thumb for his components.

- Most flowmeters contain three wires in the plug: a ground, a power, and a signal wire.
- A flowmeter should have an arrow on the device indicating the direction of fluid flow.
- The flowmeter must have 10*flowmeter I.D. of straight pipe upstream and downstream.
- Avoid turns and extra components in-line with the flowmeter to increase accuracy.

New Raven flowmeters contain a tag that displays the calibration number for the unit on it. As seen in the Figure 35, the calibration number for the unit is 1370. This number signifies that it takes 137 pulses of the meter to equate to one gallon of fluid. New products providing this calibration number can be directly placed into the mixing station and the number can be entered in the algorithm.

Figure 35. Calibration number on tag.

However, N_2 Line Solutions did not have the luxury to attain flowmeters with the calibration number tag. Therefore the team calibrated its own flowmeters using varying flow rates from 10 to 100 gallons per minute. The team could not produce consistent flow rates lower than 10 gallons per minute without using the pump and a restricting valve so low flow data was not attained. The pulses were average for each flow rate and compared to the volumetric value on a mass basis. The level of accuracy of the scale used was plus or minus 0.2 pounds and had a maximum load capacity of 660 pounds. Calibration curves were developed for two flowmeters. The first is a Raven M100 2" flowmeter that monitors the total volume within the system and the second meter was a Raven P60 1.5" flowmeter. The manufacturer metering range for the M100 meter is 3-100gpm and the P60 meter reads from 2-66gpm. The functions for the meters were nearly 100% linear for both meters, but N_2 Line Solutions fears there may be non-linearity associated with the lower bounds of the flowmeters. Although more investigation and tests should be conducted a low flow rates for custom calibration functions, N_2 Line Solutions did not pursue those tests as the function represented the projected flow rate range that the system is designed to operate in. The calibration function for the M100 two inch flowmeter is shown in Figure 37 below and the function for the P60 one and a half inch chemical meter is shown in Figure 38.

Figure 36. Producing flowmeter calibration curves.

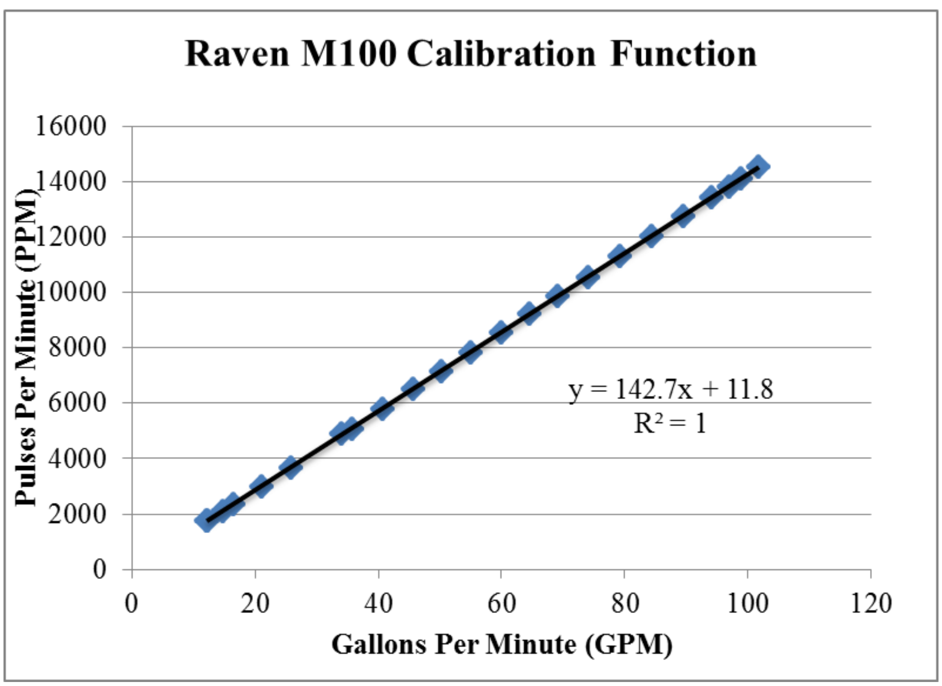


Figure 37. M100 total volume flowmeter calibration curve.

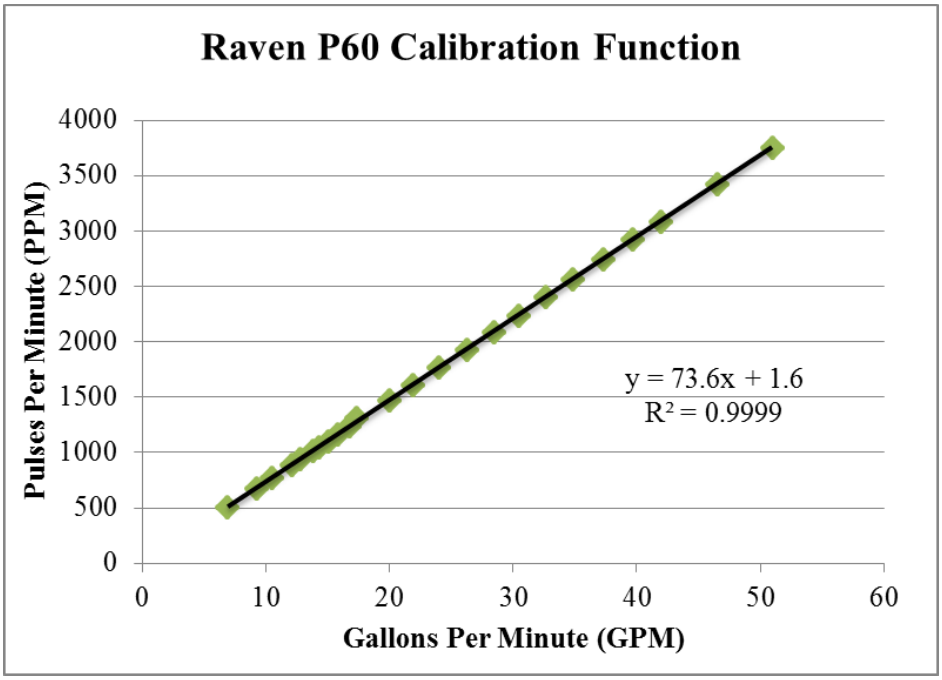


Figure 38. Chemical injection flow meter calibration for expected flow rate range.

Valve Response and Timing

After N_2 Line Solutions developed calibration curves for the flowmeters to be used in the fast-fill station, the team then looked at the response time associated with the two inch ball valves. The valves to be used were repaired and rewired to match factory settings. The response time, that is the time it takes for the valve to fully close from the open position, was measured and determined to be 1.4 seconds.

Figure 39. Repairing valves and timing cycling.

After testing the valve performance in various circumstances, the team determined that too much fluid passes through the valve while it closes, particularly at high flow rates. In addition, the function for the amount of fluid passing through the valve at increasing flow rates is not linear. So, the team determined that it would take incremental flow rates in terms of Pulses per Second (PPS) as the valve closed. To do this, the team used the software to close the valve a percentage of the total range based on time. The team also varied pump speed to increased flow and repeated the test for 10, 20, 30, and 40 Hz. The Figure below shows the flowrate of fluid through the valve as it closes. In order to predict the amount of fluid that passes through a valve as it closes, the flow must be uniform with consideration to flowrate. The team determined that the flow through the valve becomes more similar for varying flow rates as the valve approaches its fully closed location. If the team closes a valve to 1.25 seconds of its 1.4 range, or about 90% closed, the volume can be more closely projected while neglecting the overall flowrate of the system.

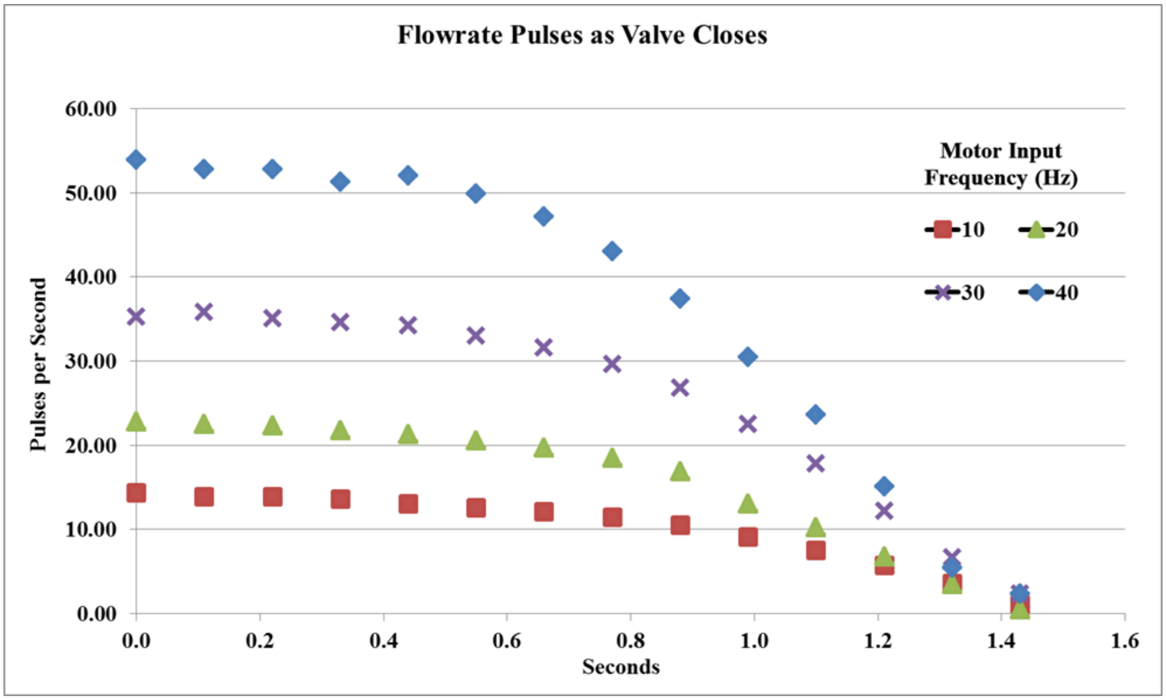


Figure 40. Fluid throughput during valve closing at varying flow rates.

Using the data attained from the response tests, the team programmed the chemical valves to move to 90% closed once 90% of the desired input volume has been attained. For instance, if a batch requires 20 gallons of Glyphosate, the valve will open and allow the chemical to reach 18 gallons prior to the valve closing 90% of the way. This restricts the flow and allows the flowmeter to monitor the volume and instruct the valve to close with less fluid passing through the system during the lag period. Although a preset value was used for the percent of volume measured before initiating partial valve close, N_2 Line Solutions suggests that the valves only initially open 10-15% of the way for volumes under 10 gallons to improve the accuracy of small volume injection.

Venturi

As previously mentioned, N_2 Line Solutions initially refuted the design concept of utilizing a venturi to draw suction on the chemical loop of the system to inject the chemical into the primary system. This was largely due to the carrier solution throughput restriction created by the venturi that would limit the system flow rate to the sprayer and prevent the team from reaching its loading time goals. However, it was discovered that a venturi bypass could be used to help alleviate the flow rate problems. The team constructed a prototype venturi and performed tests at various flow rates to determine the maximum chemical flow rate as well as the maximum total throughput flow rate. Those results are shown in Figure 38. The maximum throughput for the system with no bypass was less than 70gpm while the total chemical suction rate was up to 46gpm.

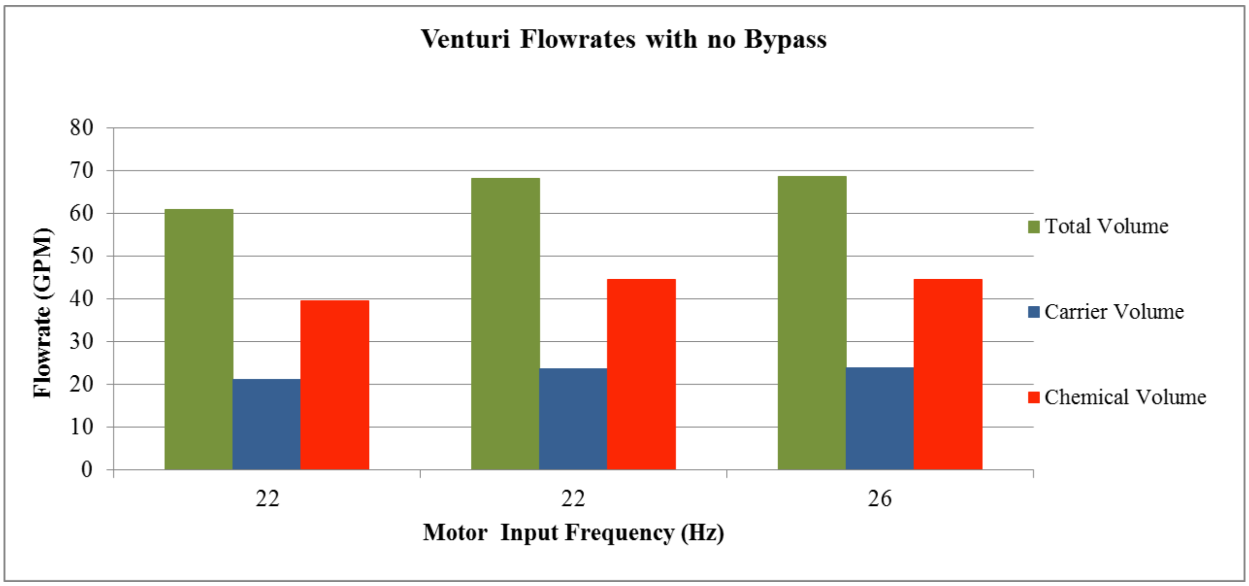


Figure 41. Total volume and chemical injection flow rates for a venturi with no bypass.

Next, the team built and installed a bypass for the venturi. The bypass manual ball valve was set to half open and the previous test was repeated for the system. The results are shown in Figure 40. The maximum total throughput volume was not reached, but the tests were ceased once the flow rates exceeded the design needs

Figure 42. Venturi test stand with bypass.

for the prototype (100gpm). The team concluded that the chemical suction rate was the same as with no bypass, but the throughput increase could be attained.

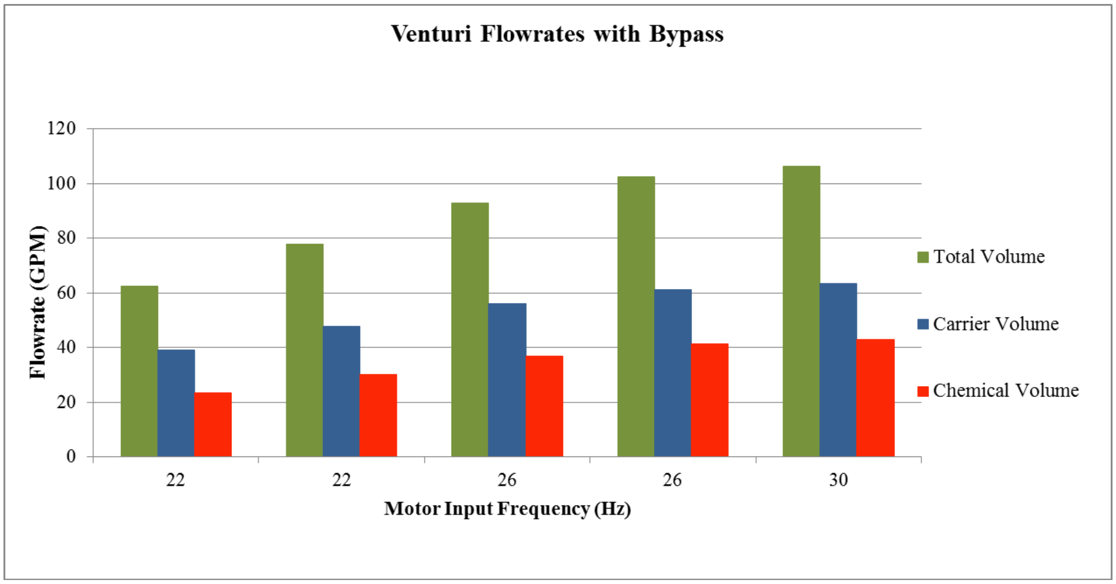


Figure 43. Total volume and chemical injection flow rates for a venturi with a bypass.

A comparison of the final system producing a batch with and without a bypass is shown in Table 10 below. With the bypass system closed and not functioning, the total flowrate is only 45gpm and 26.5 seconds elapsed for 20 gallons to travel through the venturi while the bypass allows the total flowrate to double and produce 40 gallons of carrier solution in the same amount of time in the half open position while maintaining the same chemical injection rates.

Table 11. Venturi bypass flowrate comparison for total volume.

Venturi Bypass Comparison						
Pump Speed (Hz)	**Bypass Position****	**Input Volume (gal)**	**Measured Volume (gal)**	**Volume Error**	**Time Elapsed (sec)**	**Estimated GPM***
30	Closed	20	20.1	0.50%	26.52	45.5
30	1/2 Open	40	40.2	0.50%	26.94	89.5

*Shows increased flowrate of solution to sprayer.
**Manual valve on venturi bypass set to closed (90 degrees to flow) or 1/2 open (45 degrees to flow).

Cleanout

One of the requirements of the automated chemical mixing project was to provide a rinse function to clean the system of chemical once it has been metered to reduce the residue available to contaminate the next batch. An effective Clean in Place (CIP) system on the AutoBatch mixing station provides a great competitive advantage.

An alternative discussed was using a pneumatic compressor to push remaining product out of the system and into the sprayer, but the team was concerned with inflicting air pockets in a liquid system that contains flowmeters and it would additionally require a compressor for the system. Instead, the team installed a bank of solenoid valves on the fresh carrier solution line to circulate uncontaminated solution into the chemical sub system after the chemical has been metered. The team used Viton Remcor 2100b solenoid valves on hand that are available through Raven or Schaben Industries. This is a 2.4amp, 12 volt valve with a 10gpm max flow rate as shown in Figure 44. Then, the team calculated the total volume of the subsystem for adding just one chemical as shown in Figure 45. Although the venturi would not allow the system to be left completely full of chemical, the team designed for this event as a means for its factor of safety.

Figure 44. Viton solenoid valve for cleanout cycle.

IBC 1			Loop	
Tee	0.0816		Tee1	0.0816
1.5" Reducer	0.0153		18" Hose	0.2447
2" Reducer	0.0272		45 Deg 4"	0.0544
6" Pipe	0.0816		Venturi (6")	0.0816
Flowmeter	0.0816		Wye (6")	0.0816
6" Pipe	0.0816			
1.5" Reducer	0.0153			
2" Reducer	0.0272			
Meter Volume	**0.4112**		**Loop Volume**	**0.5439**
Total Volume	**0.96**	**Gallons**		

Figure 45. Maximum liquid volume of chemical subsystem for one product.

IBC 1			IBC 2		Loop	
Tee	0.0816		Tee	0.0816	Tee1	0.0816
1.5" Reducer	0.0153		1.5" Reducer	0.0153	Tee1	0.0816
2" Reducer	0.0272		2" Reducer	0.0272	18" Hose	0.2447
6" Pipe	0.0816		6" Pipe	0.0816	45 Deg 4"	0.0544
Flowmeter	0.0816		Flowmeter	0.0816	Venturi (6")	0.0816
6" Pipe	0.0816		6" Pipe	0.0816	Wye (6")	0.0816
1.5" Reducer	0.0153		1.5" Reducer	0.0153		
2" Reducer	0.0272		2" Reducer	0.0272		
Meter Volume	**0.4112**		**Meter Volume**	**0.4112**	**Loop Volume**	**0.6254**
Total Volume	**1.45**	**Gallons**				

Figure 46. Maximum liquid volume for two products to be cleaned out of subsystem.

Using just one chemical, the maximum cleanout volume is about one gallon where the system would increase by half a gallon with every additional chemical port as shown in the Figure 43. Next, the team determined how long the cleanout cycle would take based on the number of chemicals used for the batch load for varying flow rates through the solenoid. It was determined that the actual flow rate of the prototype cleanout system is just five gallons per minute, while the valve is capable of producing up to ten gallons per minute. The corresponding cleanout time is shown below for the varying flow rate produced.

Table 12. Time required to flush chemical loop for one product.

Chemical Loop Cleanout	
Flush Rate (gpm)	**Time Requir ed (s ec)**
3	19.1
5	11.5
8	7.2
10	5.7
**Time is based on I IBC injection line	

The cleanout timing information was important to note to ensure that the maximum potential chemical volume could be injected and flushed prior to the sprayer being completely filled with the total solution. A further study was conducted based on the aforementioned chemical list and product application rates to determine the total maximum potential volume that would be injected. Based on the venturi suction flow rates, the total time required to inject the desired chemicals was calculated. Agronomic analysis revealed that the largest chemical volume required would occur when Glyphosate was used for burn down applications when the water requires Ammonium Sulfate (AMS) treatment. The maximum rate for Glyphosate is one half gallon per acre allowing that 60 gallons would be needed for a 1200 gallon spray rig applying just 10 gallons per acre. The maximum rate for AMS is also one half gallon per acre so the total product added would be 120 gallons and would require almost three minutes to inject based on 45gpm flow rate. The total volumes for four different applicator size and rate variations are shown in the spreadsheet. The total time required to inject each chemical is shown for each variation based on the maximum suggested rates.

Table 13. Maximum fill time for largest estimated dual product injection.

N2 Line Solutions' Projected Batch Volumes									
			Applicator Variations		*Batch 1*	*Batch 2*	*Batch 3*	*Batch 4*	
			Gallons of Solution Per Acre:		10	10	15	15	
			Sprayer Solution Tank Volume:		1200	1000	1200	1000	
			Number of Acres Per Load:		120.0	100.0	80.0	66.7	
Product	**Max. Rate**	**Ave. Rate**	**Units**	**Max. Rate (Gal/Acre)**	**Ave. Rate (Gal/Acre)**	**Max Product (Gal)**	**Max Product (Gal)**	**Max Product (Gal)**	**Max Product (Gal)**
Glyphosate	64	32	*fluid oz./Ac.*	0.50	0.25	60.0	50.0	40.0	33.3
Ammonium Sulfate (liquid)***	5	4	*gal/100gal*	0.50	0.40	60.0	50.0	40.0	33.3
2,4-D Amine (phenoxy)	2	1	*Quarts/Ac*	0.50	0.25	60.0	50.0	40.0	33.3
Brash/Weedmaster -> 2,4-D Amine + Dicamba	3.33	2	*pints/Ac*	0.42	0.25	50.0	41.6	33.3	27.8
Gramoxone	3	1	*pints/Ac*	0.38	0.13	45.0	37.5	30.0	25.0
Ignite--cotton rotations	40	30	*fluid oz./Ac.*	0.31	0.23	37.5	31.3	25.0	20.8
MCPA (phenoxy)	2.5	1.5	*Liters/Ha*	0.27	0.16	32.1	26.7	21.4	17.8
Paraquat {Also Gramoxone}	2.4	1.5	*Liters/Ha*	0.26	0.16	30.8	25.7	20.5	17.1
Axial XL	16.4	16.4	*fluid oz./Ac.*	0.13	0.13	15.4	12.8	10.3	8.5
ChemSurf or Squire (Non-Ionic Surfactant)	6	2	*pints/100gal*	0.08	0.03	9.0	7.5	6.0	5.0
Dicamba	0.6	0.3	*Liters/Ha*	0.06	0.03	7.7	6.4	5.1	4.3
Clarity (soluble) {Also Dicamba}	8	5	*fluid oz./Ac.*	0.06	0.04	7.5	6.3	5.0	4.2
Valor	6	2	*fluid oz./Ac.*	0.05	0.02	5.6	4.7	3.8	3.1
Harmony Extra	1	0.6	*fluid oz./Ac.*	0.01	0.00	0.9	0.8	0.6	0.5
Finesse (dry)	0.5	0.2	*dry oz./Ac.*	--	--	--	--	--	--
Olympus (dry)	3.5	2	*dry oz./Ac.*	--	--	--	--	--	--
Ammonium Sulfate (dry)	17	10	*lbs/100gal*	--	--	--	--	--	--

*Based on 40gpm venturi suction.

**Largest batch volume looks to be AMS and Glyphosate which could equal 120 gallons for a 1200ga rig putting out 10gpa. This would take almost 3 minutes. Any larger glyphosate dosages for perennial weeds would require a reduced carrier flowrate. 140 gallon batches seem to be a better upper range for the time requirements.

***AMS is used to treat water when the carrier solution is not a nitrogen fertlizer. Most RoundUp, or Glyphosate applications in OK are used with a carrier of water and the application rate is typically 22-32oz/acre (PSS-2783-2, Armstrong & Lancaster).

 # Changing the application rate or the size of the solution tank amends the number of acres sprayed per load and influences the amount of product needed.

Time Required for Batch Injection (Seconds)*			
81.8	68.2	54.5	45.5
81.8	68.2	54.5	45.5
81.8	68.2	54.5	45.5
68.1	56.8	45.4	37.8
61.4	51.1	40.9	34.1
51.1	42.6	34.1	28.4
43.8	36.5	29.2	24.3
42.0	35.0	28.0	23.3
21.0	17.5	14.0	11.6
12.3	10.2	8.2	6.8
10.5	8.8	7.0	5.8
10.2	8.5	6.8	5.7
7.7	6.4	5.1	4.3
1.3	1.1	0.9	0.7
--	--	--	--
--	--	--	--
--	--	--	--

Time Required for Glyphosate & AMS Max Rate Injection (Seconds)*			
163.6	136.4	109.1	90.9

Sec ~	*Min*
60	1:00
90	1:30
120	2:00
150	2:30
180	3:00
210	3:30
240	4:00
270	4:30
300	5:00

Design Validation

N_2 Line Solutions conducted many tests to answer the unknown questions regarding injection, metering, and chemical cleanout. The team also investigated many alternatives and design variations prior to arriving at the proof of concept design shown below.

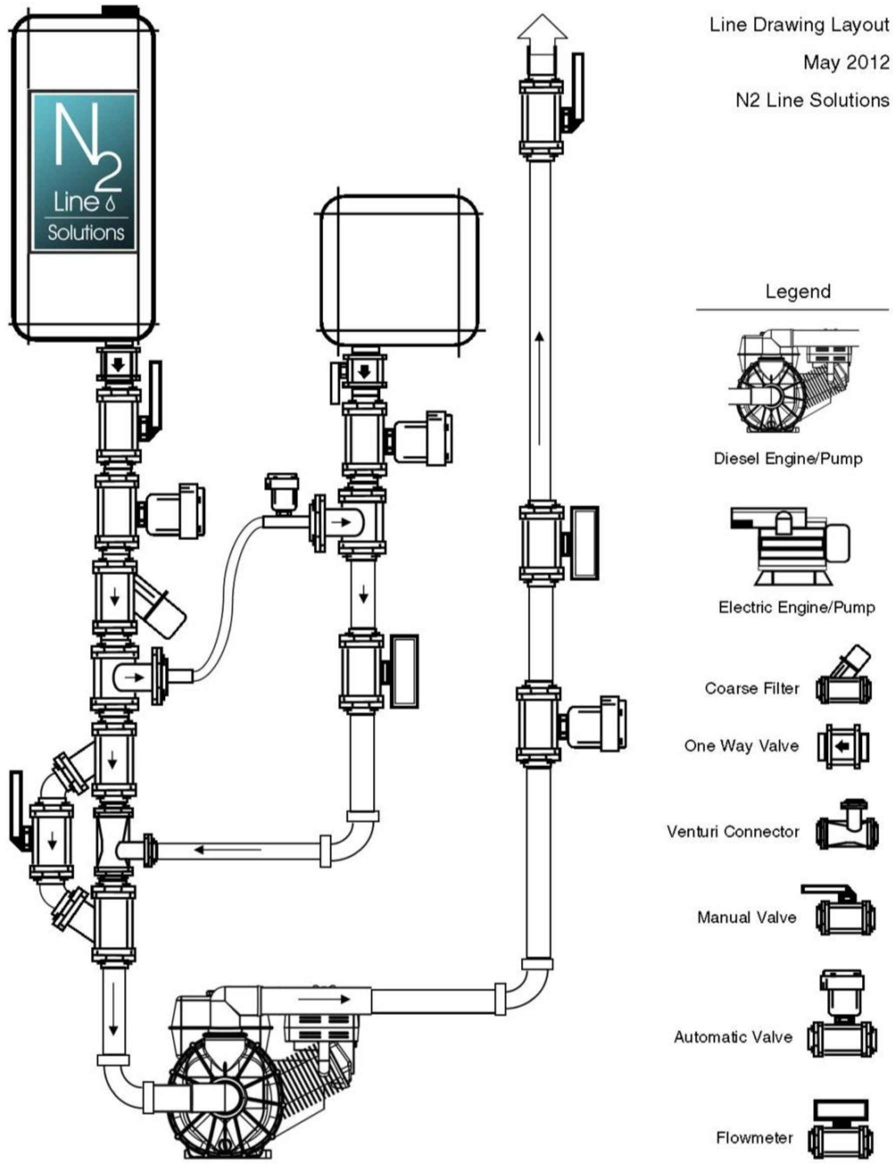


Figure 47. Final prototype design selection.

This design resembles the unit that N_2 Line Solutions constructed for demonstration of the concept. The algorithm development was based on this design, but can easily be adapted to include many chemicals instead of the single chemical shown. Upon constructing the prototype, the team continually performed tests to improve the algorithm's reliability. A major concern of this project is that it must be functional and reliable. The product must deliver the amount of volume that has been selected in order to justify the increased cost. N_2 Line Solutions conducted many simulated batch load tests to verify the AutoBatch™ system. The validation stage was based on the calibrated flowmeters and checked using a scale to verify the weight transfer. The evaluation was conducted based on the liquid flow rate automation and uncertainty (Fertell, 2008. The weight and metered volume were consistent through all validation except for the chemical injection accuracy below ten gallons were the error approached six percent. The Figure below indicates the accuracy of the total volume injected into the sprayer. The total volume is defined as carrier solution and the chemical combined. The consolidated tests revealed that the total volume accuracy is always greater than 99% and that the accuracy is best over 100 gallon total volume batches.

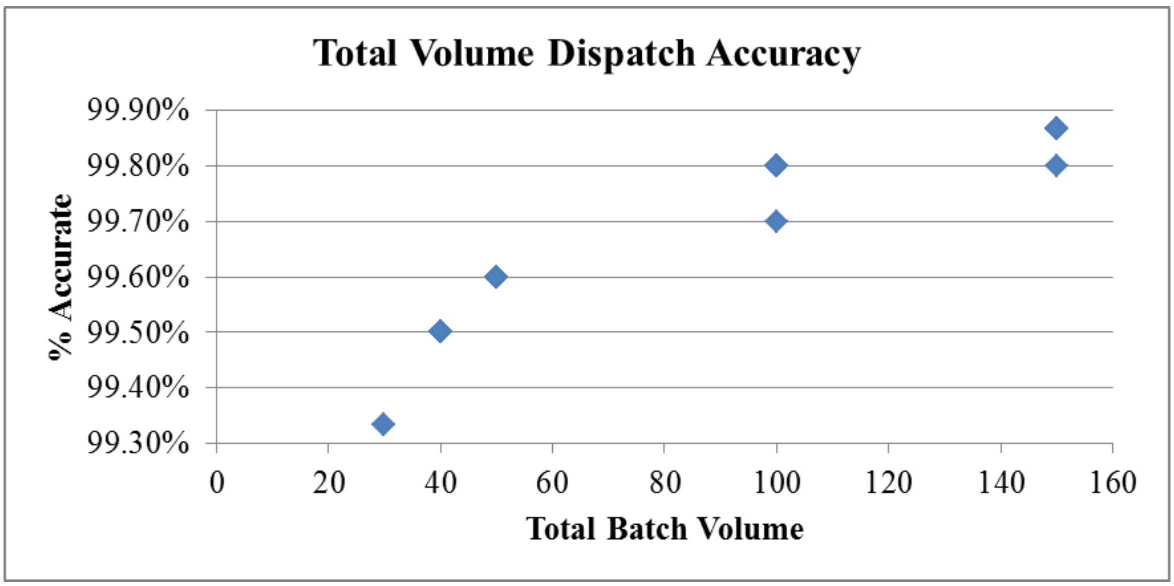


Figure 48. Total load volume batching accuracy.

The most critical metering accuracy for the AutoBatch chemical mixing station is that associated with the chemical injection accuracy for each product of the batch load. In order to provide batch constraints to Microfirm, N_2 Line Solutions conducted numerous validation tests for chemical volumes ranging from a few gallons to over fifty gallons. The team concluded that the developed algorithm allows any chemical volume of five gallons or more to be injected with only five percent error. However, further analysis revealed that increasing the injection volume to ten gallons reduced the error to just one percent for the system. The following Figure shows the accuracy of the chemical injection for volumes ranging from five to fifty gallons.

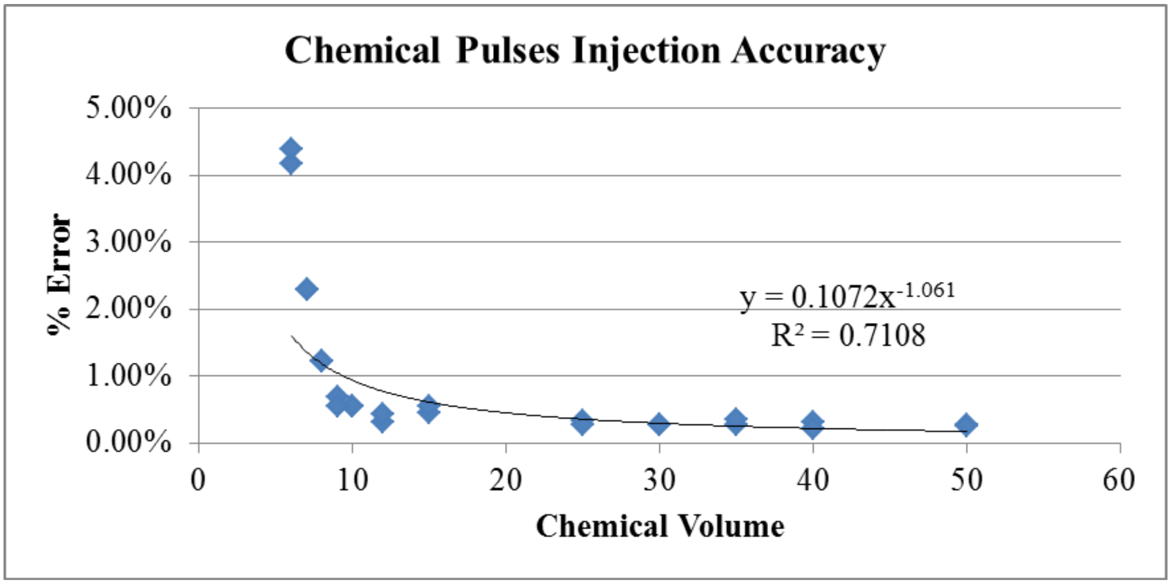


Figure 49. Chemical injection accuracy over the range of projected chemical volumes.

During testing, it was discovered that smaller batch volumes of chemical were not injected as effectively due to the time required to close the chemical valve. In order to improve the chemical accuracy for volumes less than ten gallons, N_2 Line Solutions suggests that the chemical valve only be open 10-15% of the way in the beginning. The team also noted that there was a large variation between the flowmeter readings and the mass of the volume injected for chemical batch loads of fifteen gallons or less. N_2 Line Solutions correlates the increased error with the lack of calibration data available at lower flow rates.

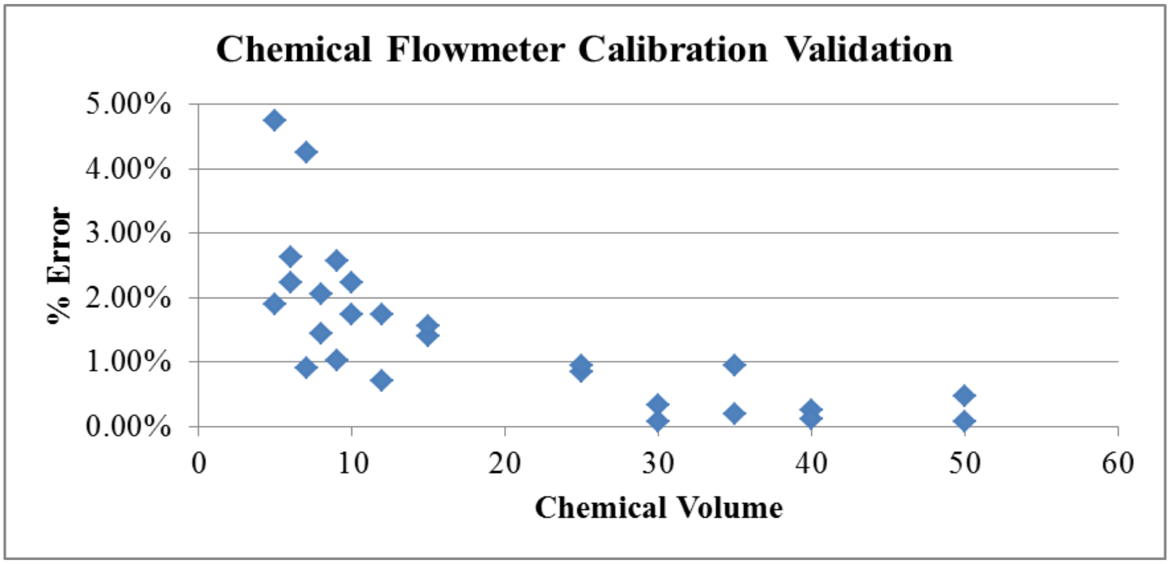


Figure 50. Low volume error associated with calibration due unexpected volumes.

Prototype Build

Although the emphasis of the chemical mixing project was to develop the algorithm and software for the system, N_2 Line Solutions also constructed a physical prototype of the design. Figure 50 shows the injection system connected to a carrier solution tank, a chemical IBC, and a poly tank that simulated a sprayer. The system utilized an electric motor and centrifugal pump to move the solution.

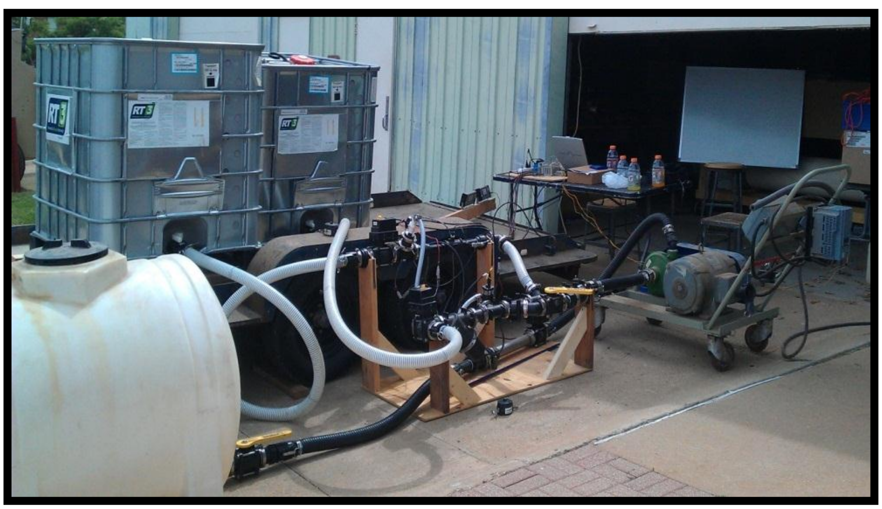


Figure 51. The model injection system produced for algorithm validation.

The AutoBatch™ injection system is adaptable for many chemical products, but the following renderings show just two chemical injection manifolds. This system also allows an inductor to be plumbed into the chemical injection loop near the venturi.

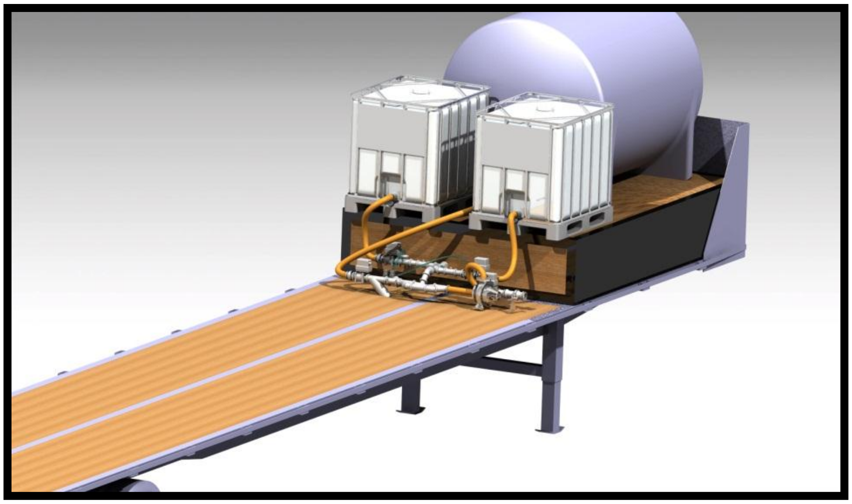


Figure 52. The chemical injection system pulls carrier solution and two chemicals into the system delivers it to the spray rig.

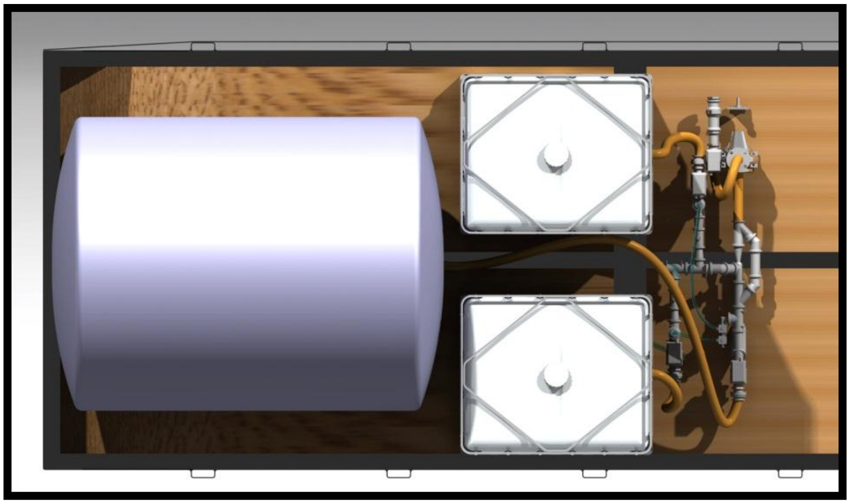


Figure 53. A top view of the system shows the compact system can be housed under a rack holding the chemical totes.

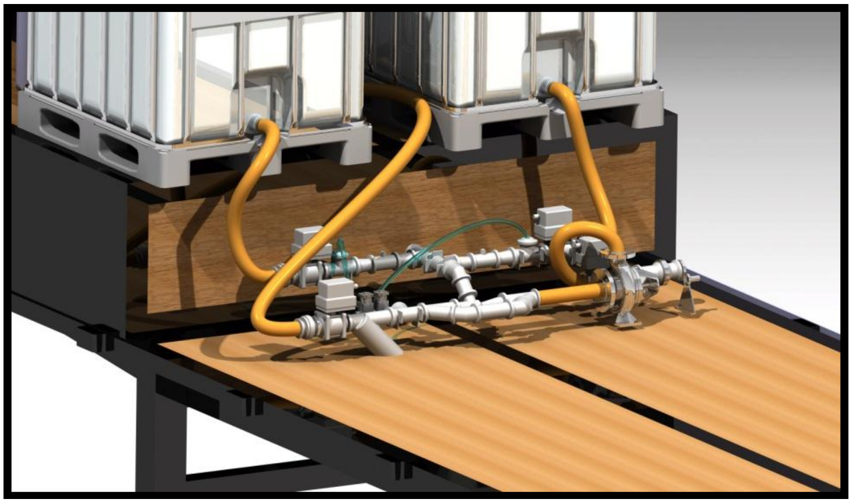


Figure 54. The system should mount to a platform transportable by forklift and can provide a filling point on either side of the trailer.

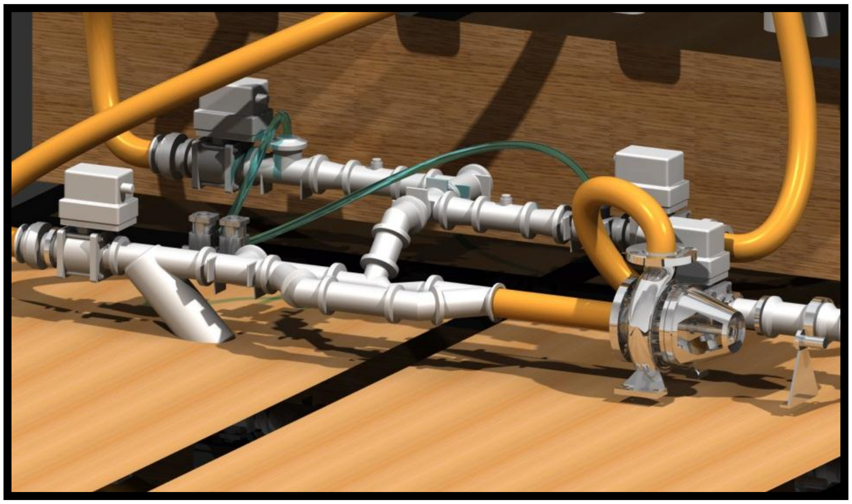


Figure 55. The solenoid valve manifold provides fresh water to the chemical loops for quick dilution of the clean in place system.

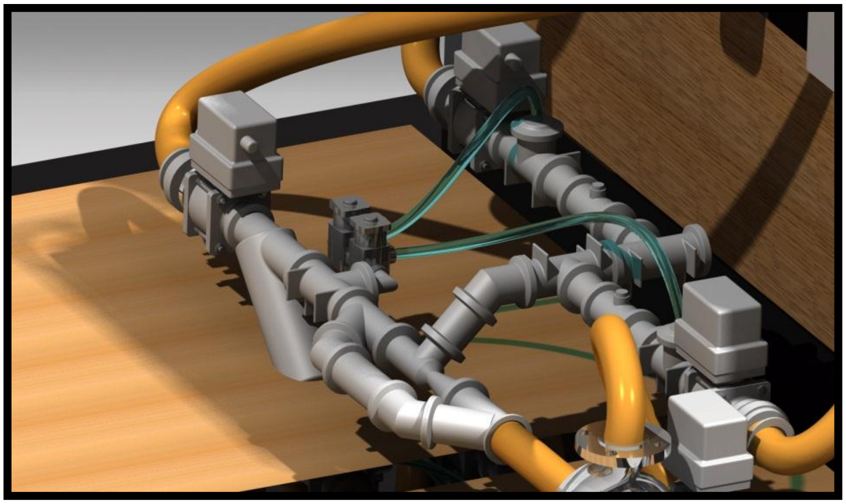


Figure 56. The renderings depict suction hose for the cleanout to provide a visual verification of the system flush.

Recommendations

N_2 Line Solutions found some potential problems with an automated system that can be avoiding through plumbing and software prevention. The following section contains recommendations for the proposed chemical injection station based on testing results, research findings, and comments taken from project observers. Some of these recommendations should be tested and integrated into the prototype prior to product release.

N_2 Line Solutions first recommends that the chemical totes should be elevated above the injection platform to increase the head pressure and maintain quick flow rates for chemical injection as the totes begin to run empty. This recommendation also includes a special consideration that allows the tendering system to sit beneath the chemical tote rack. The only restriction is the inductor, user interface, and access to the pump's motor for starting and refueling. An example rack is shown in the following figure. Two totes sit side by side and an additional rack could be placed behind the system if desired.

Figure 57. Elevated IBC rack to provide head pressure and space.

The next recommendation is for radio frequency identification (RFID) tags to be used on the chemical totes and read by the interface to ensure the proper chemical is located in the right location. This helps ensure the desired chemical is the one that is being injected into the system. Until this technology is more readily available to the industry, Microfirm should take precautions to ensure that the chemical injection lines are marked numerically and easily visible from the interface.

The team also discovered that the system is most accurate when the hose from the tote to the injection system is primed before batches. This would be most critical once a new tote has been installed. To simulate the maximum error associated with the current design, the team installed a tote and did not relieve the air or prime the system. A ten gallon chemical volume was run and the results concluded that there would be an 8% error in chemical volume injection if the user forgot to prime the system when installing a tote. Thus, N_2 Line Solutions suggests that manual reliefs be placed near the electronic control valves on each chemical connection of the system. This allows the air to be relieved from the system and replaced with chemical. An example of an air relief on a current manual system is shown in the following Figure.

Figure 58. Manual primers help bleed air in hoses.

In addition, the design team would suggest that tank level monitoring be used to advise the user when tank levels are not appropriate to complete the batch. For instance, if an applicator needs 1000 gallons of carrier solution and 50 gallons of chemical 1, but only 700 gallons of carrier is available; a warning should appear stating the requirements cannot be met. If this scenario were to present itself with not operator warnings, two things could happen. The operator would not be aware that the solution tank was not filled all the way and spray an increased chemical rate on a reduce amount of acres, or the applicator would have to wait until more carrier solution was present to complete the filling cycle and return to the field. These same sensors should notify the user of how much chemical is available to plan to switch totes accordingly during batches. If the same chemical is connected to multiple injection ports, then the software could be revised to show the respective chemical duplicates and make up the volumetric difference with the same product from chemical port 2 in the event that port 1 runs empty.

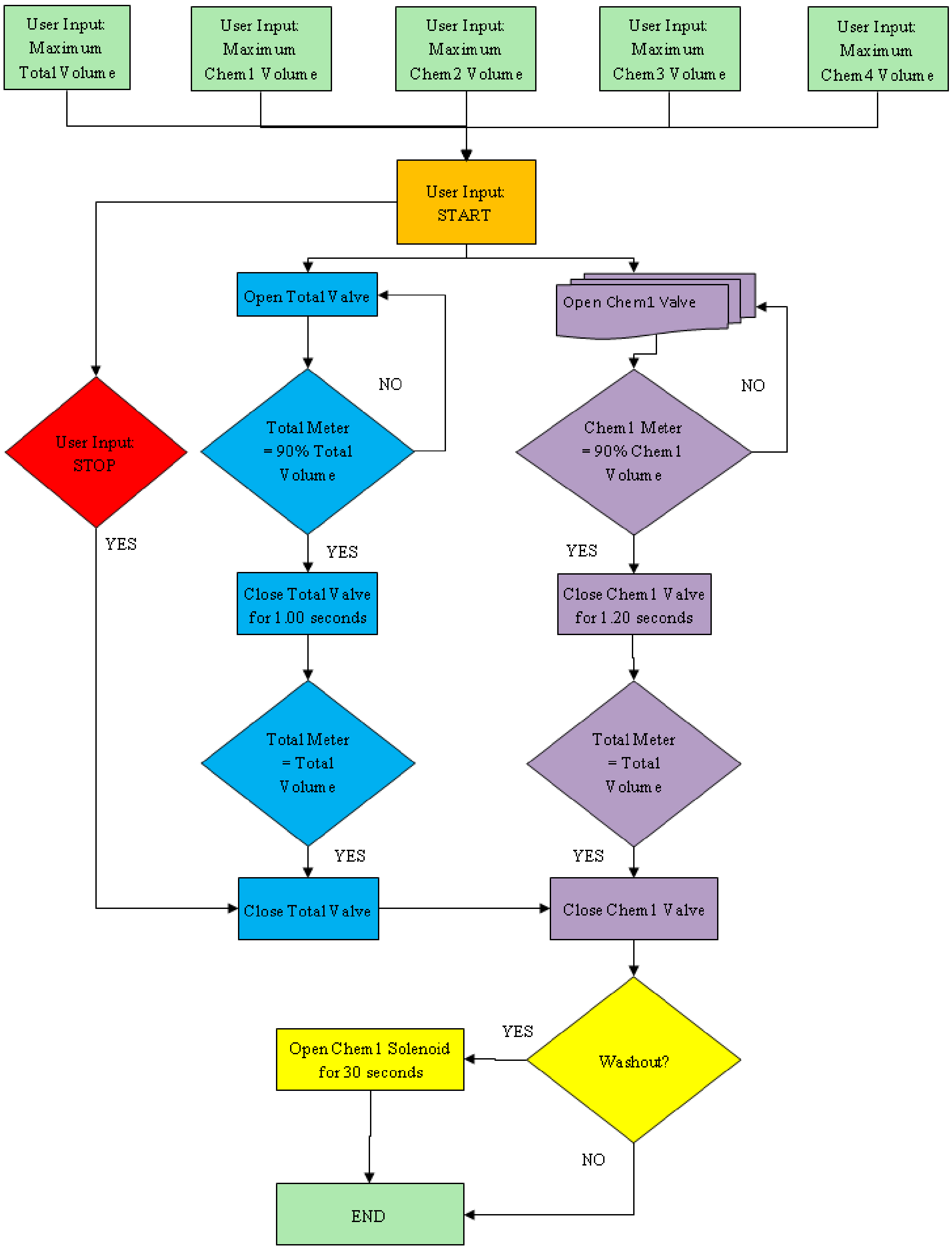
The design team also recommends that this system be predominantly used for large volume chemical injection to be most effective. However, the system could be later adapted to encompass smaller volumes of insecticides and herbicides for orchard and specialty crop applications. It is important to note that the system should be scaled down appropriately and that valve response is increasing more important as the batch sizes decrease. The current algorithm could be amended to provide specific valve correlations dependent on a range of batch sizes.

Instead of closing the valve 90% of the way for all volumes at 90% of the desired volume, this should be a higher percentage for larger volumes so that it does not slow down the fill rate. For fifty gallons of chemical, the amount of volume being transferred at the prorated flow rate is five gallons while a ten gallon batch is just one gallon. This discrepancy should be amended prior to producing the final product. The team also suggests that the client consider valve manipulation as another alternative to increasing the response time of the valves. For example, a six gallon chemical volume currently has an injection error of about 5%. The current algorithm opens the chemical valve entirely prior to closing the valve 90% of the way once 90% of the six gallons is reached. There is not enough time to complete the partial closing prior to the valve closing all the way. The team recommends that, for volumes less than ten gallons, the client instruct chemical valves to only open 25% of the way prior to closing all but 10% of the way once a set percentage of the desired volume is reached. This will reduce the flow rate of the chemical created by the venturi suction without compromising the total system flow rate and load time.

Overall, the system should be produced with as few components as possible and it should portray a similar geometry to the one shown in the previous renderings. Simplicity is very important for this application and special consideration should be given to maintaining a highly robust product that is not susceptible to chemicals or environmental conditions.

A simplified version of the algorithm developed for the project is shown as a figure on the next page while the detailed code was delivered to the client.

Algorithm


User Input: Maximum Total Volume
User Input: Maximum Chem1 Volume
User Input: Maximum Chem2 Volume
User Input: Maximum Chem3 Volume
User Input: Maximum Chem4 Volume
User Input: START
Open Total Valve
Open Chem1 Valve
NO
NO
User Input: STOP
Total Meter = 90% Total Volume
Chem1 Meter = 90% Chem1 Volume
YES
YES
YES
Close Total Valve for 1.00 seconds
Close Chem1 Valve for 1.20 seconds
Total Meter = Total Volume
Total Meter = Total Volume
YES
YES
Close Total Valve
Close Chem1 Valve
YES
Open Chem1 Solenoid for 30 seconds
Washout?
NO
END

Financial Analysis

Budget

The following Table is the bill of materials for the prototype construction of the AutoBatch™ chemical injection system. Per client request, numerous components were borrowed to develop the system proof of concept and refine the process for algorithm development.

Table 14. Bill of materials for prototype system.

Actual Development Costs Incurred			
Prototype AutoBatch™ Automated Mixing System Skid			
COMPONENT	**UNITS**	**PRICE/UNIT**	**TOTAL COST**
Banjo Sprayer Fittings	1	$220.79	$220.79
PVC Test Stand Hardware	1	$35.00	$35.00
Venturi	1	$63.29	$63.29
Venturi Bypass	1	$84.06	$84.06
Check Valves**	3	$11.68	$35.04
Hose**	50	$1.76	$88.00
Hardware Shipping	1	$15.28	$15.28
Hardware Shipping**	1	$35.93	$35.93
3 Phase 50amp Power Cord	2	$163.15	$326.30
12 Volt Battery Power Supply	1	$150.00	$150.00
Gasoline	1	$8.00	$8.00
R&D Labor***	1120	$10.00	$0.00
10hp Westinghouse Electric Motor	1	$0.00	$0.00
2" Ace Pump	1	$0.00	$0.00
5.5hp Gas Engine with 2" Pump	1	$0.00	$0.00
2" Electric Ball Valves	3	$0.00	$0.00
2" M100 Raven Flowmeter	1	$0.00	$0.00
1 1/2" P60 Raven Flowmeter	1	$0.00	$0.00
Microcontroller & RSLogix Software	1	$0.00	$0.00
Solenoid CIP Valve	1	$0.00	$0.00
Wiring Harnesses	8	$0.00	$0.00
User Interface	1	$0.00	$0.00
Platform Skid	1	$0.00	$0.00
IBC	4	$0.00	$0.00
Total Development Costs			**$1,061.69**
*No charge indicates items were borrowed and returned.			
**Designates that Microfirm purchased component.			
***Shows students were not compensated for system development.			

Based on the design recommendations, an updated bill of materials is shown in Table 14 per client request.

Table 15. Projected bill of materials broken down by category (Banjo, 2011).

AutoBatch™ Chemical Injection Station				
Component	**Quantity**	**Details**	**Pricing / Unit**	**Estimated System Costs**
		Power Unit		
13hp Gasoline Engine	1	13hp Honda. 3500 rpm.	1800	1800
3" Centrifugal Pump	1	Banjo 3" Wet Seal Centrifugal. 65 max psi. 350gpm		
			Power Unit Subtotal	**$ 1,800**
		Automatic Control Valves		
1 1/2" Banjo ACV	4	1.25 Second Response Time	600	2400
3" Banjo ACV	2	1.25 Second Response Time	750	1500
			Automatic Control Valves Subtotal	**$ 3,900**
		Metering Devices		
3" Banjo Flowmeter	1	14-670gpm	800	800
1 1/2" P60 Raven Flowmeter	4	2-66gpm	200	800
			Metering Subtotal	**$ 1,600**
		Chemical Cleanout		
Venturi w/ Inductor & Bypass	1	Bought Individual Pieces	900	900
Viton 2100b Solenoid Valve	4	10gpm max	130	520
			Cleanout Subtotal	**$ 1,420**
		Primary Plumbing Hardware		
3" Male Quick Connect	3	Flange to Male Connect Camlock	10	**30**
3" Check Valve	2	Prevent chemical from contaminating carrier solution	16	**32**
3" Filter/Strainer	1	Cleans particulates from damaging flowmeter	400	**400**
3" Tee	1	To mount solenoid manifold	11	**11**
3" Male Quick Connect	~	Flange to Male Connect Camlock		
3" Female Quick Connect	1	Female to Hose Barb	7	**7**
3" Suction Hose	2	18" hose to and from pump	4	**8**
3" THR to FL	2	Hose Barb to Pipe Thread for pump	7	**14**
3" HB to FL	2	from hose to flowmeter	6	**12**
3" Manifold 6" Pipe Extension	1	6 inch flanged straight pipe after meter and before valve	13	**13**
3" Check Valve	~			
3" Male Quick Connect	~	Flange to Male Connect Camlock		
			Primary Hardware Subtotal	**$ 1,947**
		Chemical Loop Plumbing Hardware		
1 1/2" Check Valve	5	Before each valve, and before venturi	12	**60**
1 1/2" Tee	7		13	**91**
1 1/2" Manifold Cap w/ 3/4" Pipe Thread	4	To insert fitting for soleonid cleanout	2	**8**
1 1/2" to 2" Manifold Reducer	1		5	**5**
45 Degrees 2" Manifold Wye	1	Connect Inductor and Chemical Loop	22	**22**
45 Degrees 1 1/2" Manifold Elbow	1	To Chemical Loop	8	**8**
2" Manifold 6" Pipe Extension	1	To Elevate Chemical Loop	6	**6**
1 1/2" Manifold 6" Pipe Extension	4	After flowmeter	5	**20**
1 1/2" 90 Degree Manifold Elbow	1	Instead of Tee for fourth and final IBC	4	**4**
3/4" Suction Hose	10	10 foot	1.5	**15**
3/4" Male Pipe Thread to Hose Barb	8	Makes four hoses	2	**16**
3/4" 90 Degree Elbow w/ Male THR	1	From Tee Cap to First solenoid	2	**2**
3/4" Female to Male Adapter	3	Connect all 4 Solenoids together (Or Purchase Manifold)	2	**6**
3/4" Cap	1	Close off 4th Valve	1	**1**
			Cleanout Hardware Subtotal	**$ 264**
		Total Projected Components Cost		**$ 10,931**

Sales and Market Projection

N_2 Line Solutions has developed a chemical injection system that provides accurate batch loads in less time than any system on the market. Due to the intrinsic algorithm development and unparalleled technological advancement in the marketplace, Microfirm has the competitive advantage to sell AutoBatch™ injection systems for the price determined. However, the customer surveys revealed that the affordability of this product is very important in their decision to utilize an automated system. The actual anticipated product budget is shown below for outsourcing all assembly with no consideration to consumed materials compared to a standard and reliable mechanical system.

Table 16. Material comparison of a manual system and the AutoBatch™ automated system.

Product Cost Comparison							
Manual Mixing System Assembly				Proposed AutoBatch™ Automated Mixing System Skid			
COMPONENT	UNITS	PRICE/UNIT	TOTAL COST	COMPONENT	UNITS	PRICE/UNIT	TOTAL COST
35ga Inductor	1	$400.00	$400.00	35ga Inductor	1	$400.00	$400.00
Primary Pump	1	$600.00	$600.00	Primary Pump	1	$600.00	$600.00
Primary Gas Engine	1	$1,200.00	$1,200.00	Primary Gas Engine	1	$1,200.00	$1,200.00
Transfer Pump	1	$800.00	$800.00	Venturi w/ Bypass	1	$175.00	$175.00
2" Valves	2	$40.00	$80.00	3" Electric Ball Valve	1	$275.00	$275.00
Metering Device	1	$200.00	$200.00	3" Electro-Magnetic Flow Meters	1	$350.00	$350.00
Battery	1	$100.00	$100.00	Battery	1	$100.00	$100.00
PVC Fittings	1	$150.00	$150.00	PVC Fittings	1	$150.00	$150.00
Platform Skid	1	$150.00	$150.00	Platform Skid	1	$150.00	$150.00
Assembly Labor	15	$12.00	$180.00	Manufacturing & Assembly Labor	15	$30.00	$450.00
Hose	75	$2.50	$187.50	Hose	50	$2.50	$125.00
IBC	4	$0.00	$0.00	IBC	4	$0.00	$0.00
				1" Electric Ball Valve	4	$200.00	$800.00
				1" Electro-Magnetic Flow Meters	4	$300.00	$1,200.00
				Solenoid CIP Valve	4	$100.00	$400.00
				Wiring Harnesses	15	$20.00	$300.00
				Electrical Box / Protection	1	$100.00	$100.00
				Controller (PLC)	1	$500.00	$500.00
				Human Interface	1	$1,500.00	$1,500.00
Total Unit Cost			**$4,047.50**	**Total Unit Cost**			**$8,775.00**
				Software Development & Rights	5	$500.00	$2,500.00
System Markup	50%	$2,023.75	$2,023.75	System Profit Margin	150%	$13,162.50	$13,162.50
Projected Selling Price			**$6,071.25**	**Projected Selling Price**			**$24,437.50**

Table 16 also depicts an additional cost for software development and algorithm usage rights. N_2 Line Solutions projects that Microfirm needs to sell twenty systems with a $2,500 software charge in order to cover the research and development expenses associated with the initialization and expansion of the software package for this product. In addition, the markup for the product has been set at 150% allowing the unit to be purchased for cheaper than the John Deere LoadCommand system.

Although N_2 Line Solutions acknowledges that many target customers will have reservations about the initial startup cost of this unit, an AutoBatch™ system is a productive return on investment Table17 projects daily production for a large, commercial applicator. The scenario assumes the applicator is spraying 1500 acres per day at 10 gallons per acre with a sprayer having a 120 foot boom and 1200 gallon solution tank. The number of tank fills is estimated at 12.5. The standard mechanical system is shown on the left and the AutoBatch™ is shown on the right. A re-fill time of 15 and 7 minutes is shown respectively. This represents the best case scenario for the manual system and the longest re-fill time expected for a large batch from the automated injection system. The labor, fuel, and machinery costs were calculated based on the spraying and re-fill time. In addition, the amount of time saved with the automated system was utilized to perform additional custom applications on 250 acres generating $1,250 of revenue. The automated system can save a large applicator over $400 per day and generate an additional $1,200 in gross revenue.

Table 17. Daily use and automated system investment justification.

Daily Return Comparison for Commerical Applicator			
Standard Chemical Shuttle System		**Proposed AutoBatch™ Automated Mixing System Skid**	
Number of acres sprayed per day:	1500	Number of acres sprayed per day:	1500
Number of acres sprayed per hour:	150	Number of acres sprayed per hour:	150
Size of sprayer tank: (ga)	1200	Size of sprayer tank (ga)	1200
Number of batch loads per day:	12.5	Number of tanks filled per day:	12.5
Average time per tank fill: (min)	15	Average time per tank fill (min)	7
Daily minutes spent filling sprayer:	188	Minutes spent filling sprayer	88
Number of daily labor hours required: (spray + fill)	13.13	Number of daily labor hours required: (spray + fill)	11.46
Potential number of acres gained per day:	0	Potential number of acres gained per day:	250.0
Revenue generated per acre:	$5.00	Revenue generated per acre:	$5.00
Potential daily revenue increase:	$0.00	Potential daily revenue increase:	$1,250.00
Daily cost of labor required to mix batches: ($12/hr)	$157.50	Daily cost of labor required to mix batches:	0
Daily cost of operator: ($20/hr)	$262.50	Daily cost of operator: ($20/hr)	$229.17
Daily cost of machine operation: ($80/hr)	$1,050.00	Daily cost of machine operation: ($80/hr)	$916.67
		Daily labor and machine savings:	$324.17
		Daily fuel savings: (10gph) ($4/ga)	$50.00
Daily cost of Manual System:	**$1,470.00**	**Daily cost of Automated System:**	**$1,145.83**
AutoBatch™ Daily Return on Investment:		**$1,624.17**	

The following assumptions were made in the previous and following examples and should be considered when analyzing the financial viability of a highly effective automated system:

Note:
Assumes carrier solution has no limitation.
Assumes each batch load is a full tank.
Assumes commercial applicator would pursue additional acres with extra time.
Assumes commercial applicator uses efficient system currently.
Assumes producer has a homemade functional system currently.
Assumes producer would not pursue custom applications.
Labor and machine costs based on applicator estimation.
Payback period based on $25,000 AutoBatch™ selling price

A similar example is shown in Table 18 for a smaller producer that owns his or her own sprayer. The scenario assumes the farmer is spraying 100 acres per day at 10 gallons per acre with a sprayer having a 90 foot boom and 1000 gallon solution tank. The number of tank fills is estimated at 15. A re-fill time of 15 and 7 minutes is shown respectively. The amount of time saved with the AutoBatch™ was not productively used for further applications. The automated system saves a small farmer over $300 per day in fuel, machine use, and labor.

Table 18. Daily use and automated system investment justification for small farmer.

Daily Return Comparison for Grain Producer			
Standard Chemical Shuttle System		**Proposed AutoBatch™ Automated Mixing System Skid**	
Number of acres sprayed per day:	1000	Number of acres sprayed per day:	1000
Number of acres sprayed per hour:	100	Number of acres sprayed per hour:	100
Size of sprayer tank: (ga)	1000	Size of sprayer tank (ga)	1000
Number of batch loads per day:	10.0	Number of tanks filled per day:	10.0
Average time per tank fill: (min)	15	Average time per tank fill (min)	7
Daily minutes spent filling sprayer:	150	Minutes spent filling sprayer	70
Number of daily labor hours required: (spray + fill)	12.50	Number of daily labor hours required: (spray + fill)	11.17
Potential number of acres gained per day:	0	Potential number of acres gained per day:	133.3
Revenue generated per acre:	$5.00	Revenue generated per acre:	$5.00
Potential daily revenue increase:	$0.00	Potential daily revenue increase:	NONE
Daily cost of labor required to mix batches: ($12/hr)	$150.00	Daily cost of labor required to mix batches:	0
Daily cost of operator: ($20/hr)	$250.00	Daily cost of operator: ($20/hr)	$223.33
Daily cost of machine operation: ($80/hr)	$1,000.00	Daily cost of machine operation: ($80/hr)	$893.33
		Daily labor and machine savings:	$283.33
		Daily fuel savings: (10gph) ($4/ga)	$40.00
Daily cost of Manual System:	$1,400.00	Daily cost of Automated System:	$1,116.67
AutoBatch™ Daily Return on Investment:		**$323.33**	

The data in Tables 19 and 20 depict the return on investment for an AutoBatch™ system. The annual acreage covered is shown and the same equipment depicted in the previous two examples was used for the annual projections. Again, the extra time saved during re-filling for the commercial applicator was used to attain more acreage while the farmer's extra time was spent with his family or completing other farm related tasks. This time, the farmer's original system took 20 minutes to re-fill instead of the previous 15 minutes in the daily example.

Table 19. Annual productivity increased and revenue generation for a commercial applicator.

Projected Return on Investment for Commercial Applicator			
Standard Chemical Shuttle System		**Proposed AutoBatch™ Automated Mixing System Skid**	
Number of acres sprayed annually:	30000	Number of acres sprayed annually:	30000
Number of acres sprayed per hour:	150	Number of acres sprayed per hour:	150
Size of sprayer tank: (ga)	1200	Size of sprayer tank: (ga)	1200
Number of batches loaded per year:	250	Number of batches loaded per year:	250
Average time per tank fill: (min)	15	Average time per tank fill: (min)	7
Hours spent filling sprayer annually:	62.5	Hours spent filling sprayer annually:	29
Number of annual labor hours required: (spray + fill)	263	Number of annual labor hours required: (spray + fill)	229
		Annual custom application acres gained with reduced fill time:	5000
		Revenue generated per acre:	$5.00
		Potential annual revenue increase:	$25,000
Annual cost of labor required to mix batches: ($12/hr)	$3,150	Annual cost of labor required to mix batches:	0
Annual cost of sprayer operator per hour: ($50/hr)	$13,125	Annual cost of sprayer operator per hour: ($50/hr)	$11,458
Annual cost of machine operation: ($80/hr)	$21,000	Annual cost of machine operation: ($80/hr)	$18,333
Annual sprayer fuel costs: (10gph) ($4/ga)	$10,500	Annual sprayer fuel costs: (10gph) ($4/ga)	$9,167
Annual Application Cost of Manual System:	$47,775	Annual Cost of Automated System	$38,958
		System Savings	$8,817
		Potential Annual Return on Investment	$33,817
		Payback Period (Years)	0.7

Table 20. Annual cost savings and time saved for a farmer's applications.

Projected Return on Investment for Grain Producer			
Standard Chemical Shuttle System		**Proposed AutoBatch™ Automated Mixing System Skid**	
Number of acres sprayed annually:	10000	Number of acres sprayed annually:	10000
Number of acres sprayed per hour:	100	Number of acres sprayed per hour:	100
Size of sprayer tank: (ga)	1000	Size of sprayer tank: (ga)	1000
Number of batches loaded per year:	100	Number of batches loaded per year:	100
Average time per tank fill: (min)	20	Average time per tank fill: (min)	7
Hours spent filling sprayer annually:	33.3	Hours spent filling sprayer annually:	12
Number of annual labor hours required: (spray + fill)	133	Number of annual labor hours required: (spray + fill)	112
		No custom applications or increased acreage potential assumed.	
Annual cost of labor required to mix batches: ($12/hr)	$1,600	Annual cost of labor required to mix batches:	0
Annual cost of sprayer operator per hour: ($50/hr)	$6,667	Annual cost of sprayer operator per hour: ($50/hr)	$5,583
Annual cost of machine operation: ($80/hr)	$10,667	Annual cost of machine operation: ($80/hr)	$8,933
Annual sprayer fuel costs: (10gph) ($4/ga)	$5,333	Annual sprayer fuel costs: (10gph) ($4/ga)	$4,467
Annual Application Cost of Manual System:	$24,267	Annual Cost of Automated System	$18,983
		Potential Annual Return on Investment	$5,283
		Payback Period (Years)	4.7

Many farmers will still to see the value of a $25,000 system that saves them just thirty to fifty cents per acre especially if they are only covering 10,000 acres annually. Yet, N_2 Line Solutions believes many producers will be forced to update current mechanical systems in the near future due to increased governmental regulations pertaining to herbicide use and chemical applications. Although no formal legislature has been issued regarding improved recording keep for agricultural applicators, society is continually faulting the industry for environmental degradation. An automated system could allow users to log every detail regarding a batch and its application and wirelessly transmit it to be stored at the home base. Additionally, the AutoBatch™ allows all users to sustain a safer work environment due to the lack of chemical exposure on the jobsite.

Impacts

Environmental

N_2 Line Solutions' fast-fill product is designed to minimize environmental impacts by reducing contamination risk. The self-contained system limits the handling of hazardous products and prevents spill occurrences and wasted chemical. With spills reduced, potential water quality benefits are significant. Federal regulations regarding the handling and application of agricultural chemicals require accurate monitoring of application rates. The system created by N_2 Line Solutions is designed to help the customer meet these requirements and regulations. Accurate, automated chemical batch dosing eliminates many of the risks associated with manual mixing. Efficient chemical batching is the primary goal of N_2 Line Solutions and the increased safety and environmental conservation is a value added benefit for producers.

Industrial

Since the dawn of the industrial age, man has been improving, simplifying and automating processes. The agricultural industry is no exception. Across the board, products are becoming more and more dependent upon technology. The chemical application industry has made tremendous strides by incorporating technology, but the process remains dependent on manual labor. By automating the mixing and delivery process of batch loads, operator efficiency increases dramatically. With minimal cost increases, a customer can save time and potentially reduce the number of laborers required to fill the sprayer. This allows a producer to increase the daily acres covered in a shorter amount of time. In the simplest terms, more acres covered means more money by generating more revenue and cutting down on overhead expenses. Improving the chemical handling aspect of agricultural application allows producers to alter equipment needs as well because the fast-fill station makes the equipment become more efficient as well. In some instances, applicators would be able to cover a field with a 90 foot boom sprayer and fast-fill station faster than they could complete it with a 120 foot boom and manual system. This leap in efficiency would revolutionize the agricultural industry yet again, and move society one step closer to marinating global food demands.

Social

The agricultural industry is steeped in pride, history, and hard work. Automation is not necessarily the first word a farmer wants to hear, nor does a famer want to see electrical wires and controllers operating everything. A farmer's livelihood may depend on his or her ability to fix breakdowns as they arise. Many farmers don't have the tools or capability to tackle electrical problems so many become scared of electronics. Problems with reliability, durability, and performance should be considered by any manufacturer, but particularly those in agriculture. Technicians are not abundant in remote or rural areas and downtime to a farmer can mean thousands of dollars in lost revenue. N_2 Line Solutions strives to design a system that meets the tough standards of the farmer while increasing efficiency. Technology is only becoming more prevalent. It seems almost apparent that automation will be the rule rather than the exception within the agricultural industry in the future, but N_2 Line Solutions must bridge the gap between today and tomorrow in order to market a product successfully that is perhaps, ahead of its time. In addition, the automated system can potentially replace human workers and the employment implications should be considered when implementing this system. However, this automated chemical mixing system provides increased field efficiency, higher profit potential, increased safety, and federal compliance.

Conclusion

N_2 Line Solutions partnered with Microfirm, Inc. to help develop technology to improve chemical batching and tendering for the agricultural industry. After careful deliberation and research, the team identified the needs of the client as well as the target customer. The primary objective of this project was to build a fast-fill platform to increase applicator efficiency in a cost effective manner. Accuracy and durability were key design concerns when developing a product to be used rigorously as a mobile mixing system. The AutoBatch™ design presented by N_2 Line Solutions includes durable components, efficient automation, and a practical, condensed layout. This automated system is designed to utilize chemicals available in large volume totes. In addition, granular products or small volume containers can be slurried and injected into the solution using the inductor. This flexibility allows the system to be adapted between specialized customers and systems, and allows each specific applicator a wide range of options. With an accessible user interface, a once tedious and dirty process is automated and simplified for the applicator. In the agricultural production industry, time is profit and the AutoBatch™ chemical injection platform can save a large, commercial applicator over one hundred minutes of idle time each day. The product offers a completely automated fill and clean in place system that provides a detailed account of each batch loaded. This improved means of recording keeping will help improve customer relationships through increased documentation for applicators and also serve as a preventative measure for liability issues related to chemical drift and/or environmental concerns. N_2 Line solutions recommends that valves with quicker response times, less than 1.25 seconds, be utilized in applications where small volumes are necessary. This product is 99% accurate for chemical injection of chemical volumes that exceed ten gallons and can load a 1000 gallon batch of treated water and fifty gallons of chemical in under three minutes. Further development and field testing will help Microfirm finalize the algorithm for scenarios with high volume and increased flow rate batches.

Bibliography

Agmanager. 2010. Evaluating Self-Propelled Sprayer Ownership with the OwnSprayer Spreadsheet. Available at: http://www.agmanager.info/farmmgt/machinery/Tools/OwnSprayer.pdf. Accessed 10 November 2011.

Agrotop Spray Technology. 2012. Novelety! QuantoFill M multi-proportioner http://www.agrotop.com/en/component/content/article/247-novelety-quantofill-m-multi-proportioner

Arduino. 2012. Arduino Electronics: Available at: http://www.arduino.cc/. Accessed 21 October 2011.

Armstrong, J. Sarah Lancaster. 2011. "*Herbicide How-To: Maximizing glyphosate activity*." Oklahoma Cooperative Extension Service. PSS-2783. Available at: http://extensionnews.okstate.edu/archived-articles-1/2011-archived-articles/PSS-2783%20Maximizing%20glyphosate%20activity.pdf. Accessed 16 February 2012.

Banjo. 2011. Banjo Catalog. Banjo Corporation. Available at: http://www.banjocorp.com/2011/2011%20Banjo%20Catalog.pdf. Accessed 19 February 2012.

Dan D Rental. 2012. Trailers. Available at: http://sites.ararental.org/portals/dandrental/itemsforrent/Trailers.aspx Accessed 19 October 2011

Divelbiss Corporation. 2012. Control Products. Available at: http://www.divelbiss.com/Products/CatDetails.asp?ProdCatID=1. Accessed October 21, 2011.

Fertell, Richard. 2008. Liquid Flow Rate Automation & Uncertainty – Staying Drier. 16th IMEKO TC4 Symposium. Sept. 22-24, 2008, Florence, Italy. Available at: http://www.imeko.org/ publications/tc4-2008/IMEKO-TC4-2008-054.pdf. Accessed 16 February 2012.

JD Skiles Company. Available at: http://www.jdskiles.com/pitstopsprayertrailer.html. Accessed 19 October 2011.

John Deere & Company. Self-Propelled Sprayers. Available at: http://www.deere.com/wps/dcom/en_US/products/equipment/self_propelled_sprayers/self_propelled_sprayers.page. Accessed 19 October 2011.

NASS. 2010. National Agricultural Statistics Annual. National Agricultural Statistics Service. Available at: http://www.nass.usda.gov/Publications/Ag_Statistics/2010/. Accessed 16 February 2012.

NZIC. The Production of Phenoxy Herbicides. New Zealand Institute of Chemistry. Available at: http://nzic.org.nz/ChemProcesses/production/1J.pdf. Accessed 16 February 2012.

OAFF. 2012. Oklahoma Agriculture, Food, and Forestry. Pesticide Applicator. Available at: http://www.ok.gov/~okag/cps-pest.htm. Accessed 8 December 2011.

OCES. 2012. Oklahoma State University. Division of Agriculture and Natural Resources Extension Service. Available at: http://www.oces.okstate.edu/. Accessed 8 December 2011.

OSUPSS. 2012. Oklahoma State University Plant and Soil Sciences. Nitrogen Use Efficiency. Available at: http://nue.okstate.edu. Accessed 7 December 2011.

Penton Media, Inc. 2012. Farm Industry News. Available at: http://farmindustrynews.com/sprayers/high-capacity-self-propelled-sprayers-0. Accessed 20 October 2011.

PLC Trainer. 2012. RSLogix 500. Available at: http://www.plctrainer.net/RSLogix500.pdf. Accessed 8 December 2011.

PorTable Tank Group. 2012. Water Storage Tank. Available at: http://www.water-storage-tank.com/ poly-tank-for-drinking-water.html. Accessed 19 October 2011.

Raven Industries. 2005. *Cable Wiring Diagram*. Sioux Falls, SD. ISBN 016-0159-460.

Raven. 2011. Sidekick Pro Direct Injection. Raven Industries. Available at: http://www.ravenprecision.com/sitecore/content/RavenSite/Products/Application%20Controls/Sidekick%20Pro%20Direct%20Injection.aspx. Accessed 16 February 2012.

Reibel, Jennifer. New Technology Driving Growth in Sprayer Sales. Available at: http://www.farm-equipment.com/pages/Features---NewTechnology-Driving-Growth-in- Sprayer-Sales.php. Farm Equipment. Accessed 7 December 2011.

Rockwell Automation. MicroLogix 1200 Control System. Available at: http://ab.rockwellautomation.com/Programmable-Controllers/MicroLogix-1200#/tab2. Accessed 8 December 2011.

Schaben. 2012. Schaben Industries Catalog. Schaben Industries. Available at: http://schabenindustries.com/pageflip/catalog.html. Accessed 16 February 2012.

Stone, Marvin. 2012. Oklahoma State University Biosystems & Agricultural Engineering. Available at: http://biosystems.okstate.edu/home/mstone/pindex.html. Accessed 8 December 2011.

USEPA. 2012. Certification and Training of Pesticide Applicators. U.S. Environmental Protection Agency. Available at: http://www.epa.gov/oppfead1/safety/applicators/applicators.htm. Accessed 8 December 2011.

USEPA. 2012. Clean Water Act. U.S. Environmental Protection Agency. Available at: http://www.epa.gov/ agriculture/lcwa.html#Summary. Accessed 8 December 2011.

USEPA. 2012. Laws and Regulations. U.S. Environmental Protection Agency. Available at: http://www.epa.gov/pesticides/regulating/laws.htm#fifra. Accessed 8 December 2011.

USEPA. 2012. Storage and Disposal. U.S. Environmental Protection Agency. Available at: http://www.epa.gov/pesticides/regulating/storage.htm#farmers. Accessed 8 December 2011.

Appendices

Appendix A. Initial project information and client request.

Appendix B. N_2 Line Solutions Gantt chart.

Appendix C. Team meeting notes.

Appendix D. Patent references and details.

Appendix E. Flowmeter specifications.

Appendix F. Venturi and Bypass.

Appendix G. Solenoid data sheet.

Appendix H. Agricultural statistics from USDA.

Appendix I. Pit-Stop competitive pictures.

Appendix J. Original sketch from November and April.

Appendix K. Review of injection pumps.

Appendix L. Liquid flow and metering validation procedures.

Appendix M. Raven components spec sheets.

Appendix N. IBC regulations.

Appendix O. Chemical property comparison.

Appendix P. Chemical list and required batch sizes.

Appendix Q. Signal amplification circuitry.

Appendix R. Process and design development.

Appendix S. Data collection and results analysis.

AutoBatch™

Chemical Injection System

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Collin Boettcher

Eric Lam

Meredith Shiflet

Biosystems & Agricultural Engineering
Oklahoma State University
April 26, 2012

Client

μFirm
Embedded System Development
CAN/J1939 Systems

Microfirm Inc.
Stillwater, Oklahoma 74074

- MicroFirm Inc.
  - Mr. Kent Dieball & Dr. Marvin Stone
  - Specialize in agricultural electronics, automation, sensing technologies
    - Greenseeker
    - AIM Command

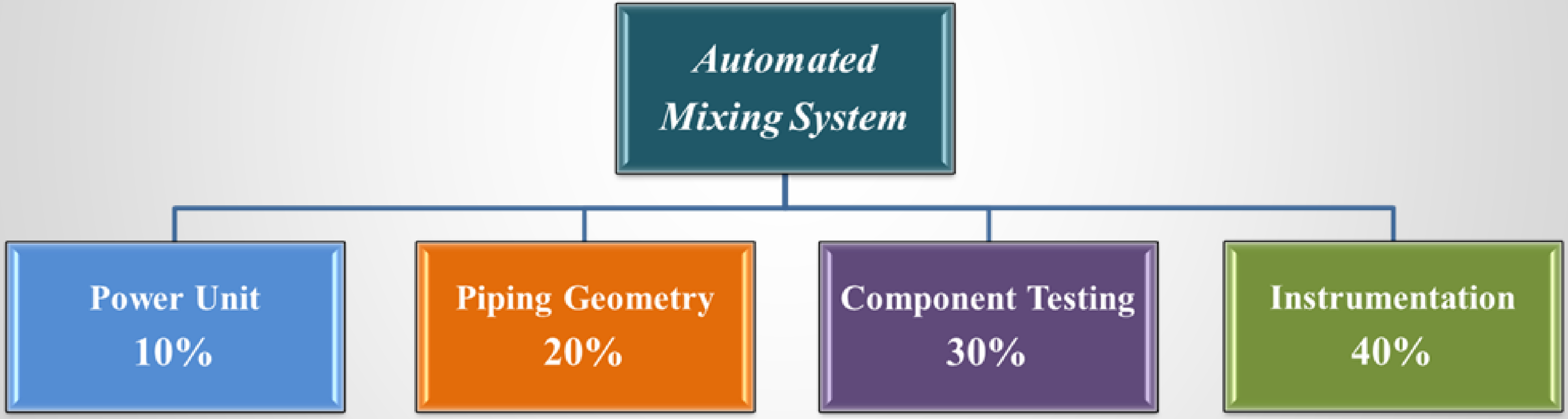
Automated Batch Chemical Injection System

- Design a conceptual prototype
  - Mobile, automated tendering station for agricultural chemical applicators.
- Automated System provides:
  - Reduced Mixing and Filling Time
  - Reduced Handler Chemical Exposure
  - Increased Functionality and Constancy

Deliverables

- ✓ Design a prototype automated chemical injection station with clean in place module
- ✓ Provide a system composed of "off the shelf" components
- ✓ Develop an algorithm to automatically meter and inject products during a batch operation based on user inputs
- ✓ Verify injection and fill volume accuracy within 3%

Work Breakdown



Task List

- Fall
  - Client orientation
  - Problem identification
  - Market research
  - Component analysis
  - Project clarification
  - Reporting
  - Design approval
- Spring
  - Finalize deliverables
  - Purchase components
  - Testing and evaluation
  - Data analysis
  - System validation
  - Financial assessment
  - Final reporting

Industry and Market Research

- Herbicide usage increase
  - No-till, reduced tillage, rotational cropping, etc.
  - 2004-2009: Oklahoma herbicide use increased 19% (NASS 2010)
- Emphasis on non-point source monitoring (EPA)
  - Need for improved record management
- Regional Batch Injection Volumes
  - Up to total volumes of 150 gallons

Customer

- Large scale chemical applicators
  - Sprayer with 90-120 ft booms
  - Acreage
    - Farmer: 10,000 acres/season
    - Commercial: 30,000 acres/season

Similar Competition

- JD Skiles Pitstop, Atwood, KS
  - Efficient, mobile volumetric mechanical system

- John Deere & Co. – LoadCommand
  - Automated coupling mechanism
- No Directly Related Competition

Common Product Hardware

- Gasoline engine
- Centrifugal pump
- Measuring device
- Control valves
- Inductor
- Intermediate bulk containers (IBC)
- Supply tank

Experimental Design

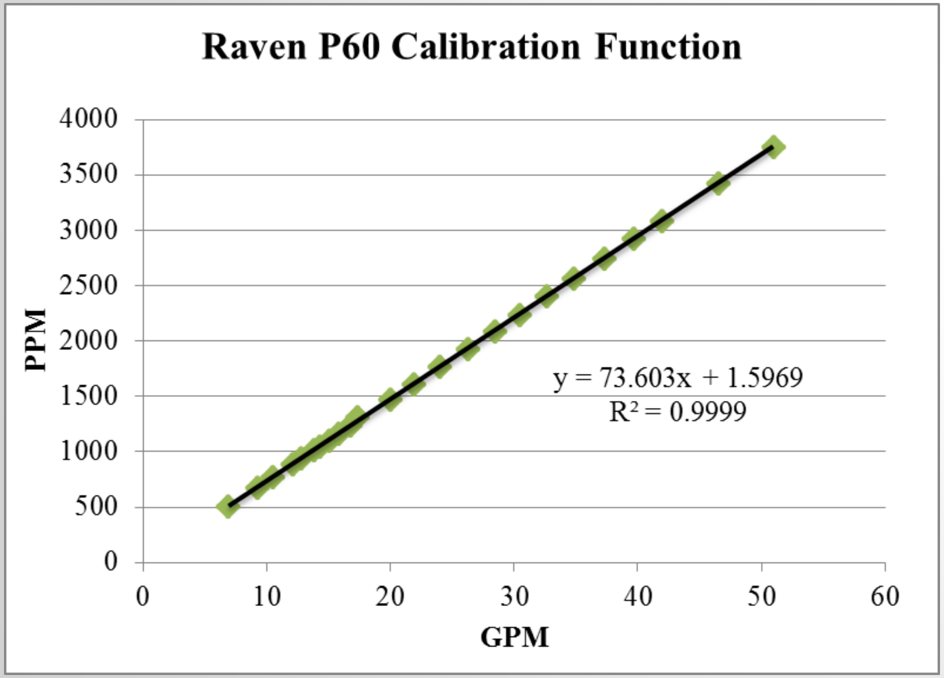
- Calibration
- Valve response
- Software development
- Automation sequencing
- Hardware compatibility
- Piping configuration
- Venturi injection
- Clean in place

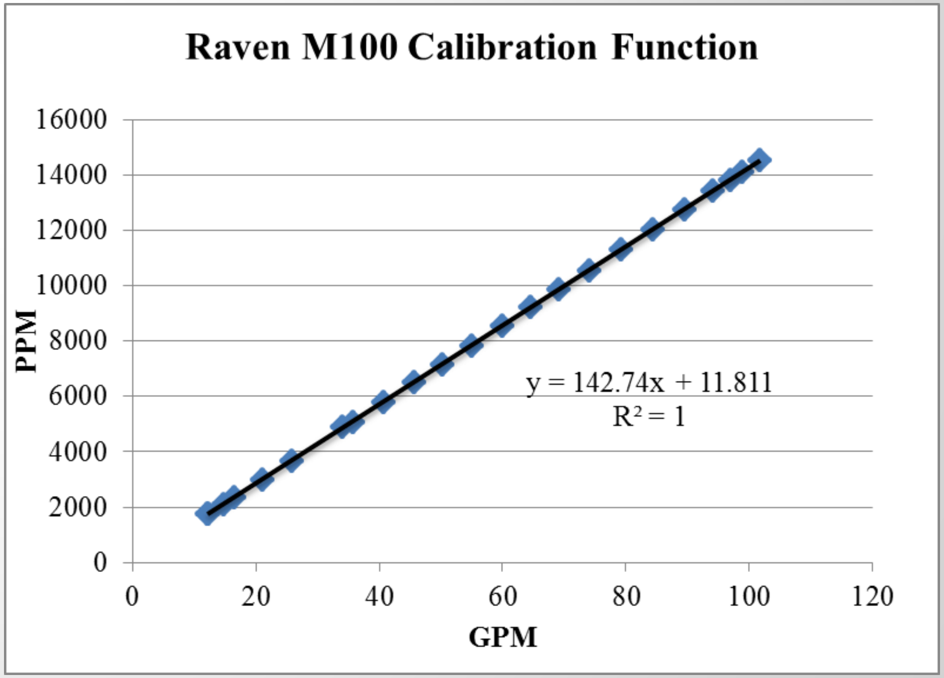
Testing

- Electronic components
  - Signal Amplification
  - PLC Response Rate
  - Wiring Modification
  - Relay Controls
- Software Development
  - PLC nomenclature
  - Compatibility
  - Human Machine Interface (HMI)

Testing

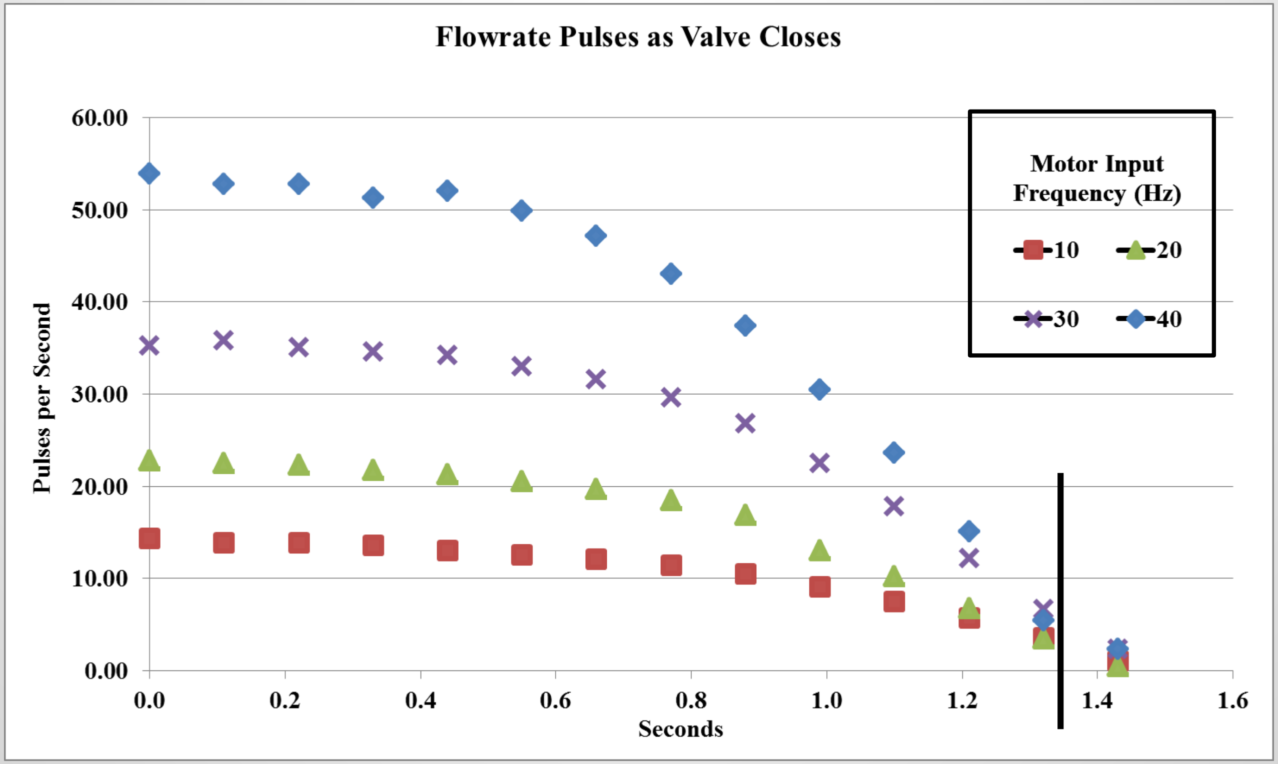
- Flowmeter calibration





Testing

- Chemical valve response to improve accuracy
  - Prepay at fuel pump

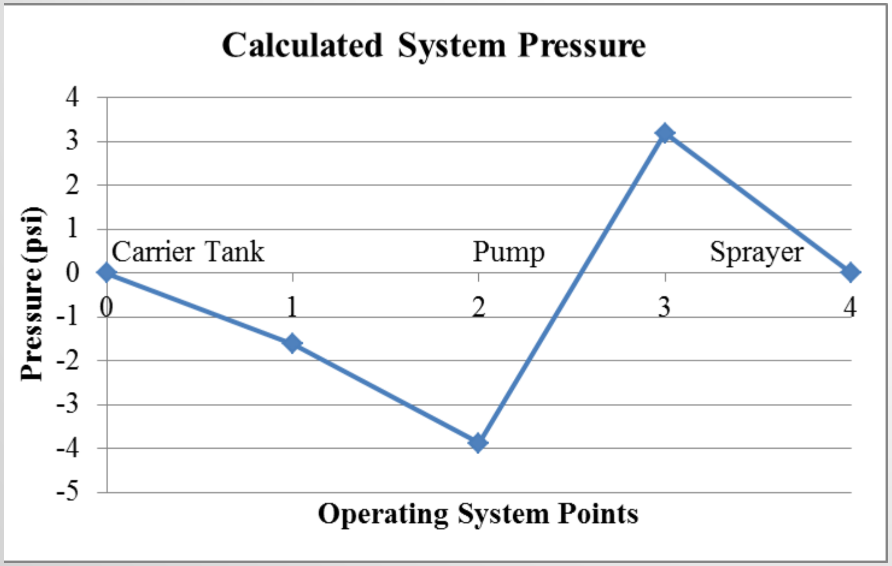


Testing

- Fluid Mechanics
  - Analyze pressure drops
  - Calculate for varying elevations
  - Aid in pump sizing

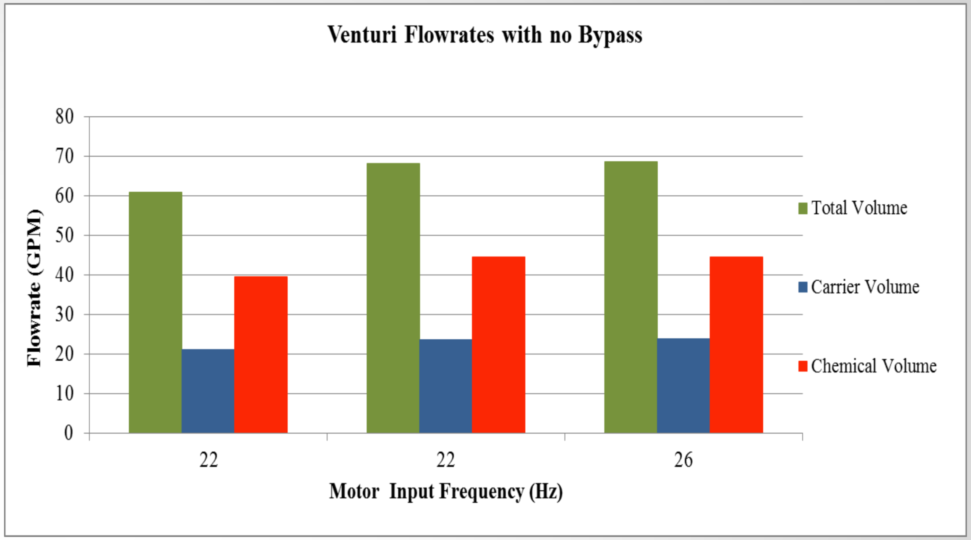
$$h_L = \sum K\left(\frac{V^2}{2g}\right)$$

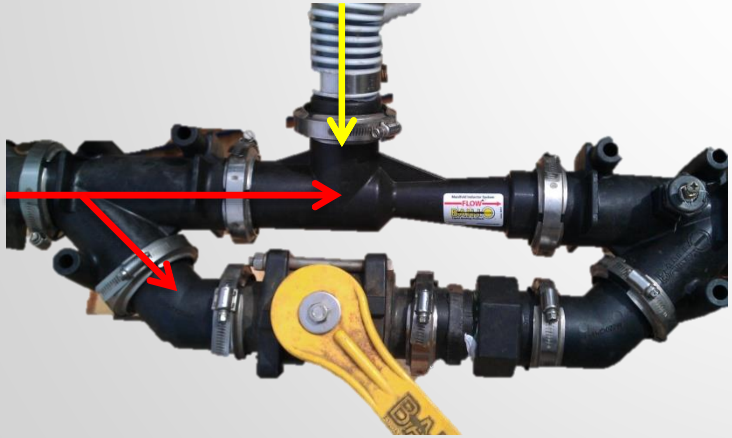
$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 + h_p = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$$

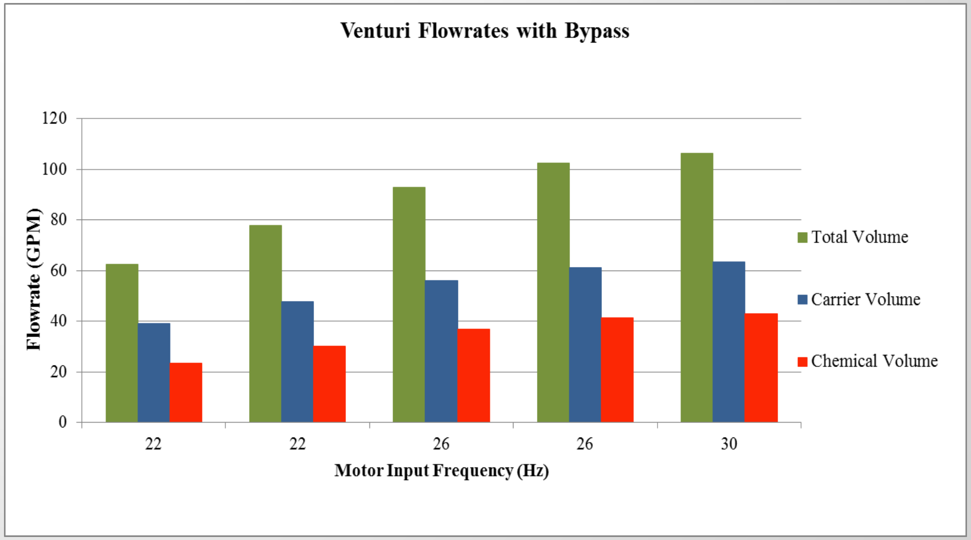


Testing

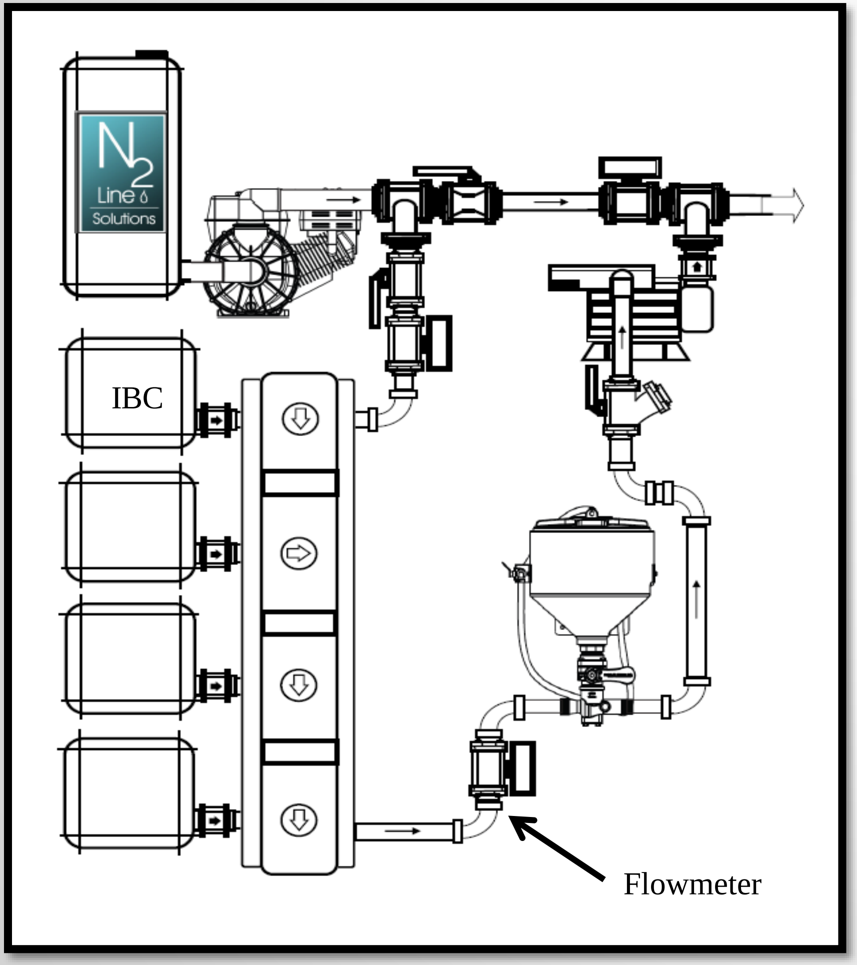
- Venturi
  - Bypass is necessary for desired flow rates







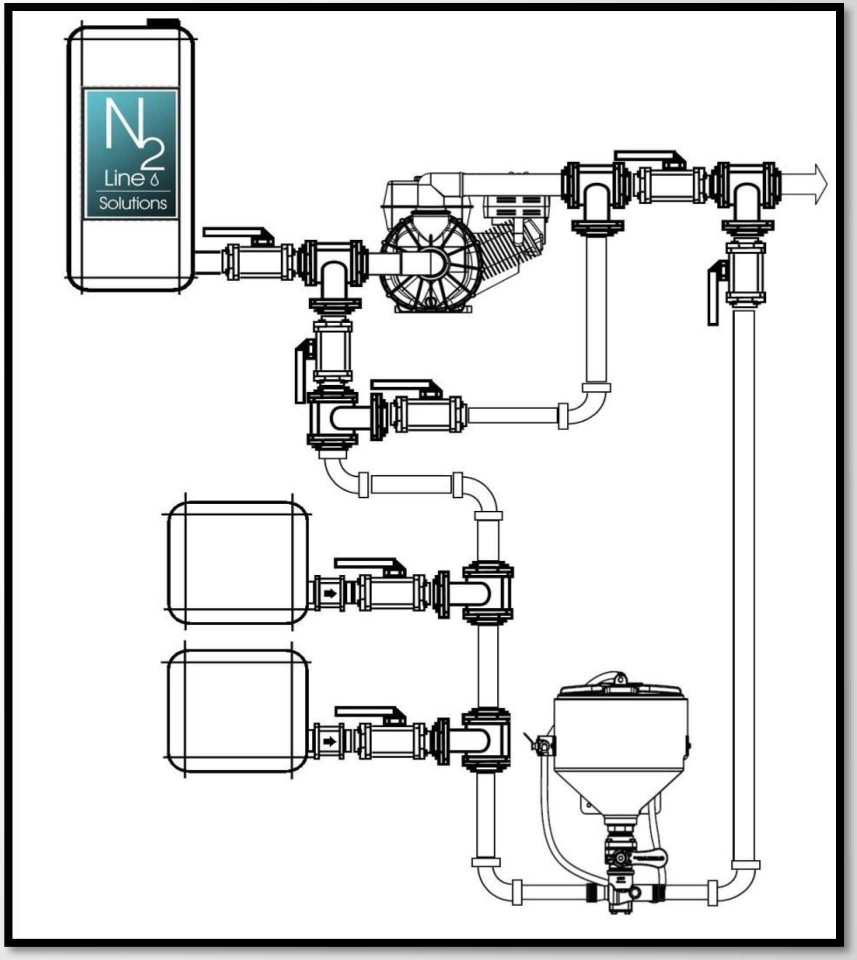
Design Selection- Alternative 1



- Expensive Secondary Pump
- Flowmeter Differential Measuring
- Compounding Component Error
- Ineffective Cleanout with Reduced Total Volume Flow

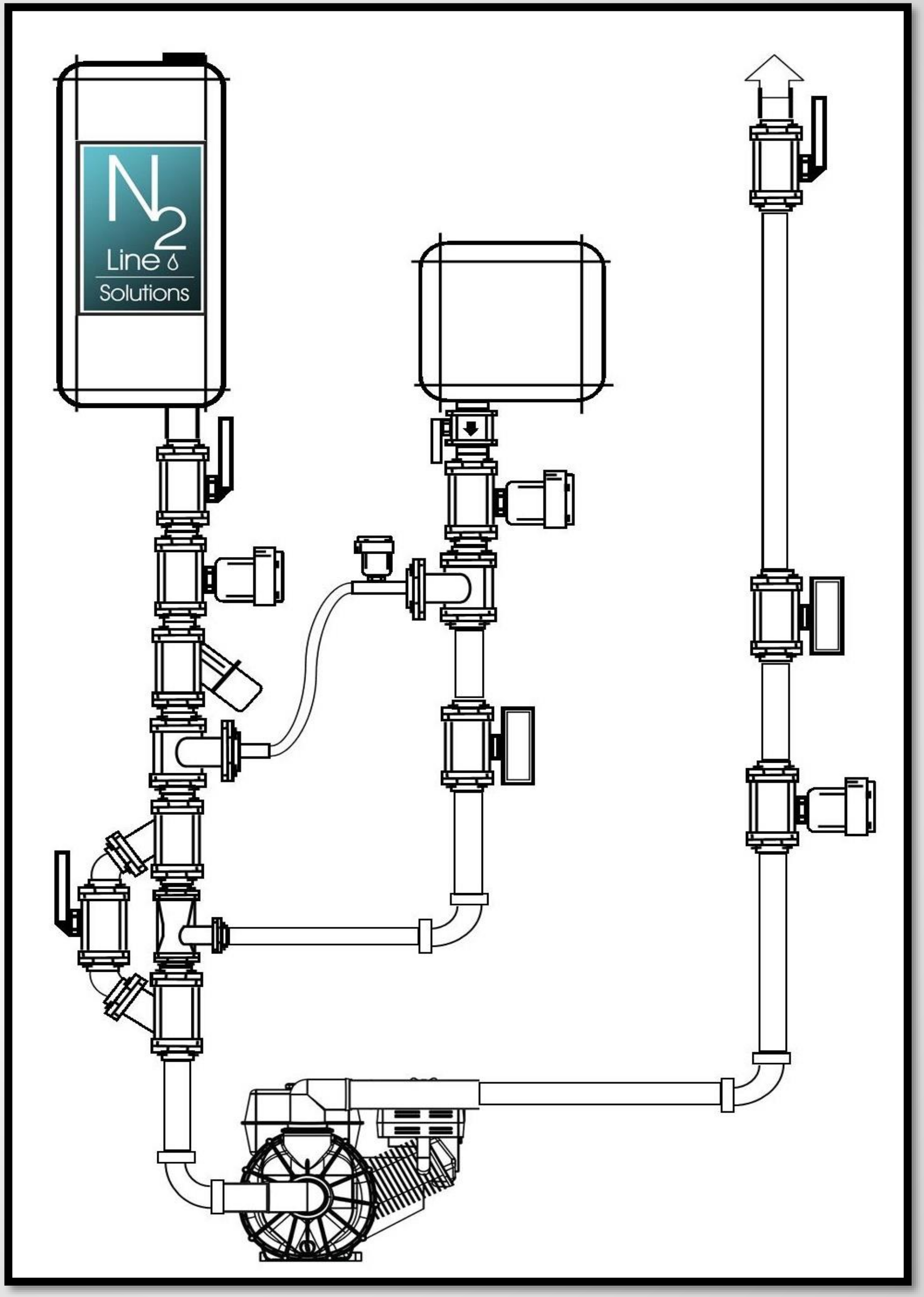
Design Selection- Alternative 2

- Not Enough Head Pressure for Chemical Injection
- Larger Diameter Secondary System
- Poor Cleanout Results
- Presented Automation Difficulties
- Excessive Components and Plumbing

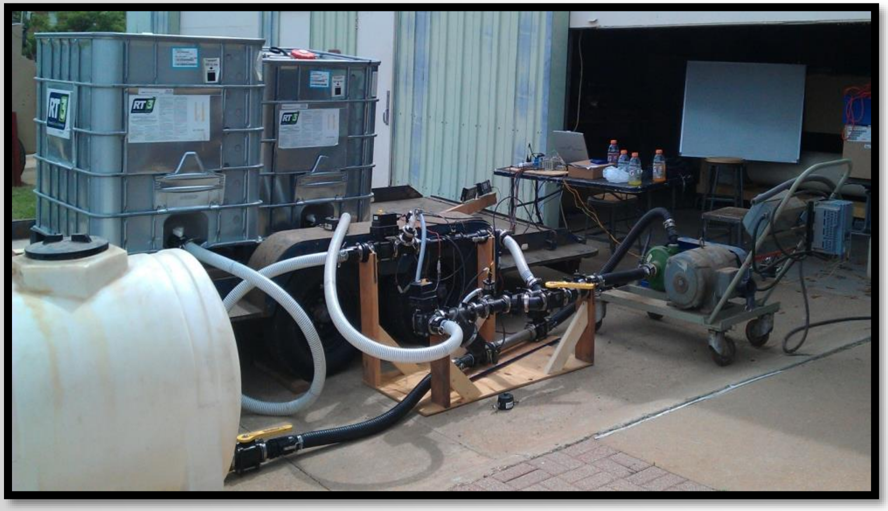


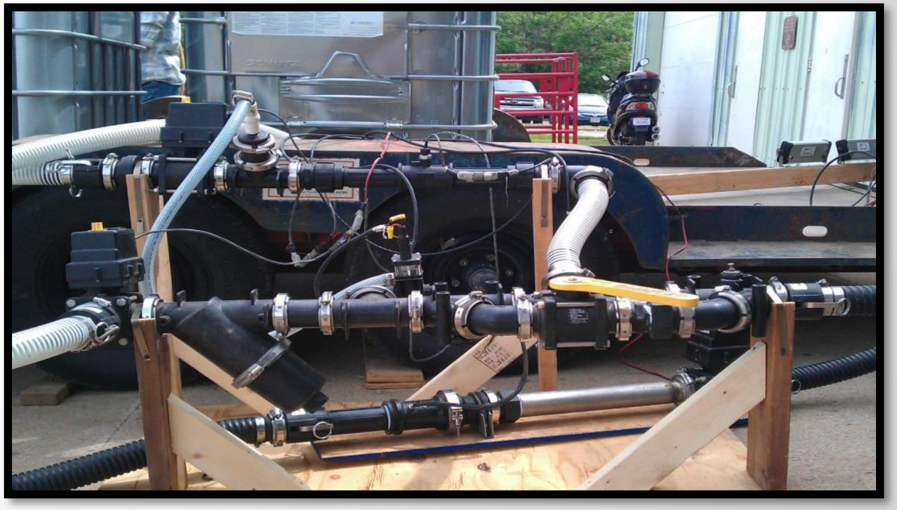
Final Design

- One Pump and Motor
- Individual Chemical Metering Devices
- Expandable to multiple totes
- Venturi Injection with Bypass
- Solenoid Valve Cleanout System

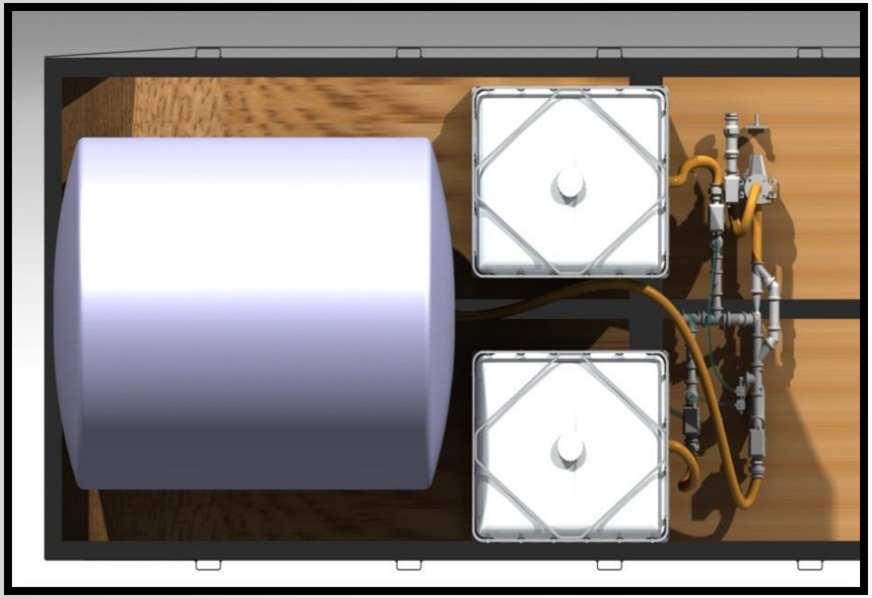


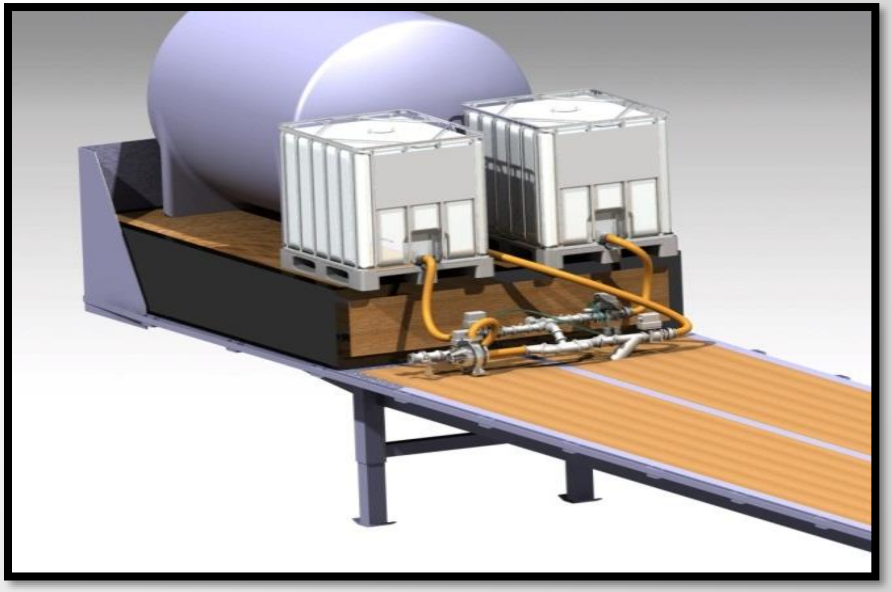
Final Design



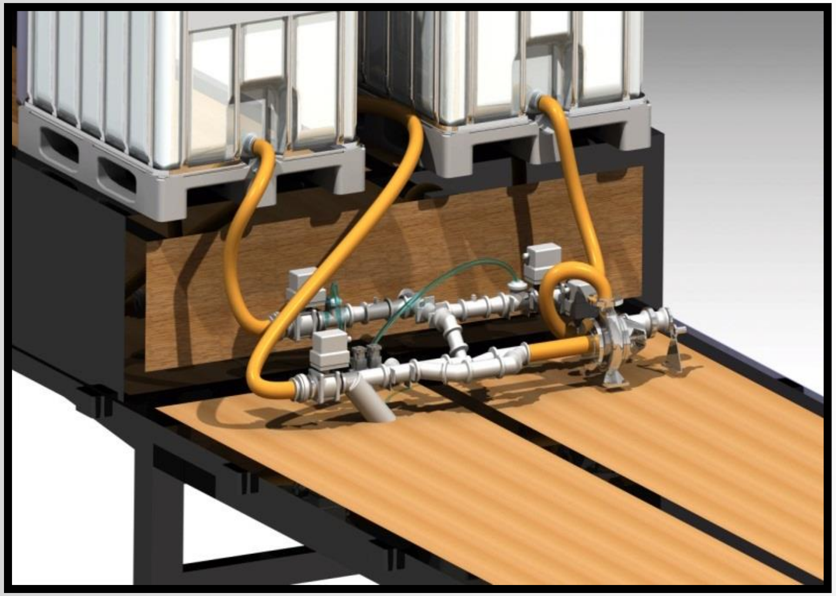


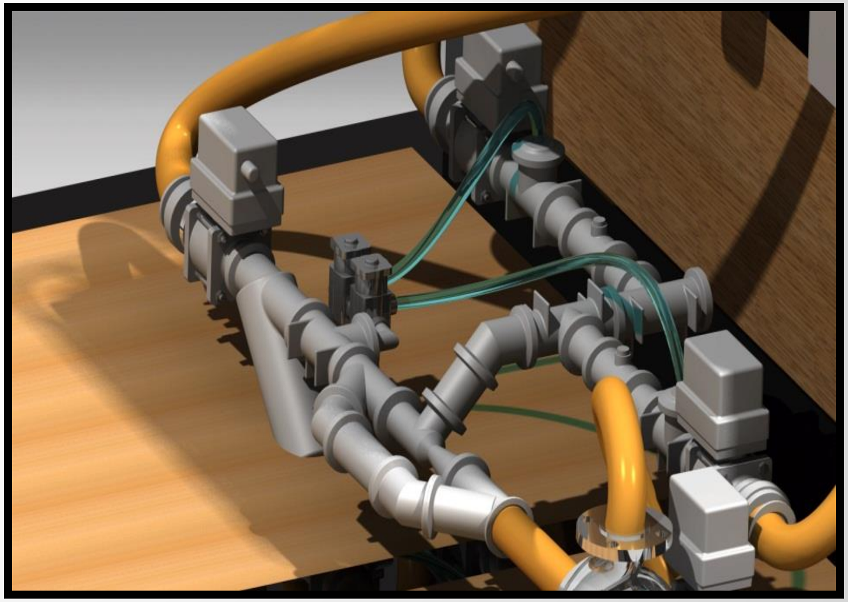
Final Design CAD





Final Design CAD

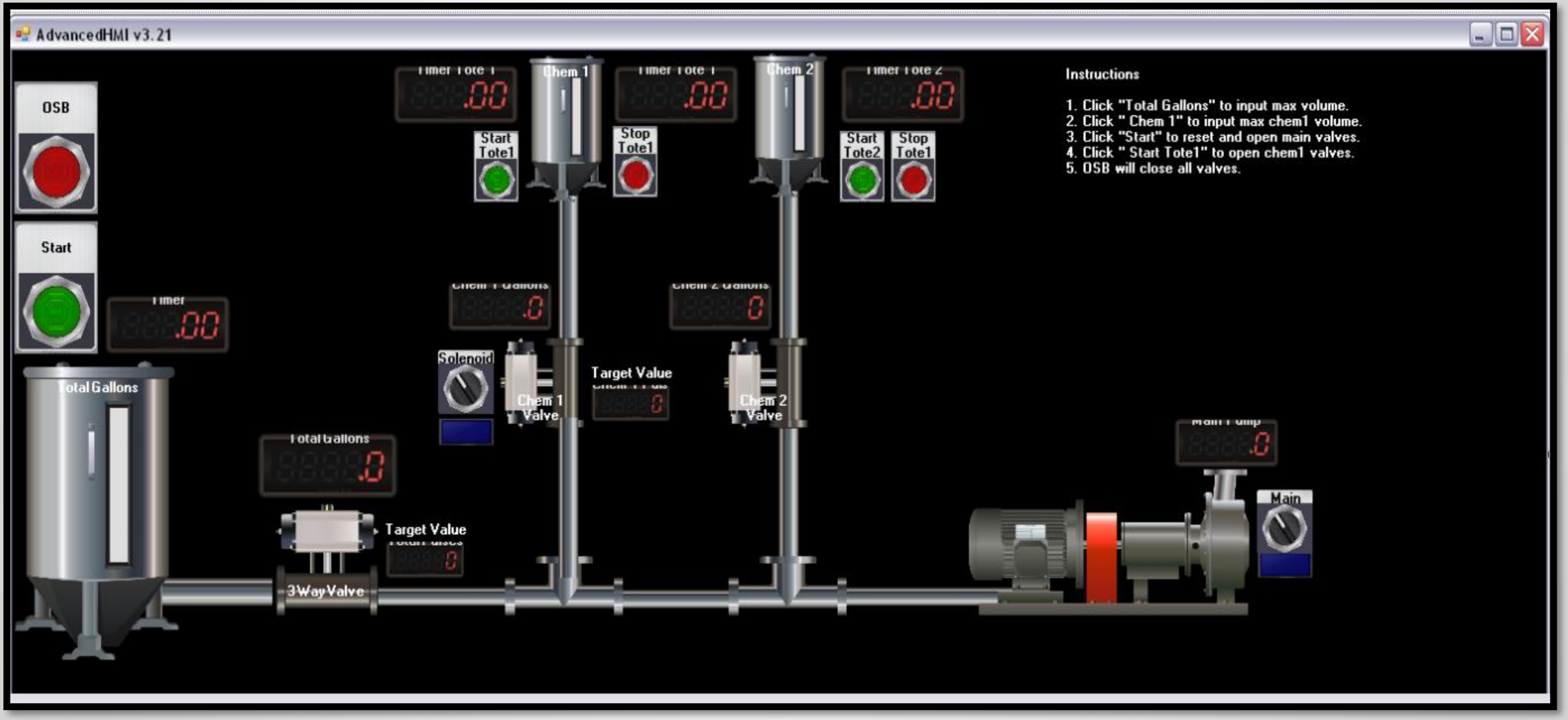




Design Recommendations

- Flowmeters
  - Electromagnetic meters only measure liquids
    - May allow for pipe size reduction
- Pump
  - 300+ gpm to meet desired load time goals
- Electronic valve response
  - Further algorithm development for small volumes
- Totes placed at higher elevation than venturi
  - 24-36” for increased head psi & spatial orientation

Operational HMI

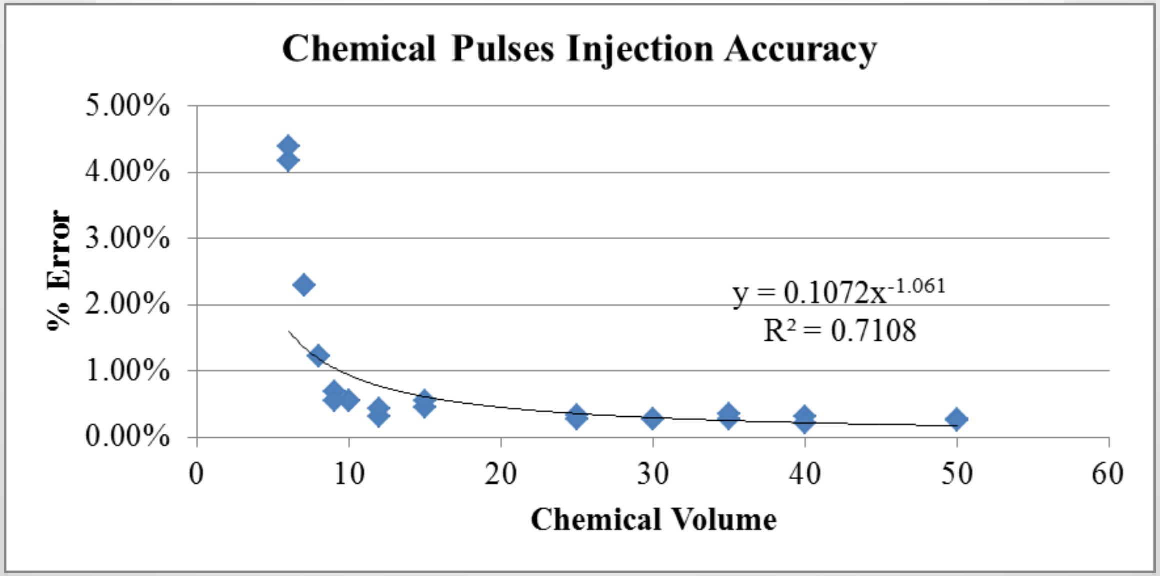


Interface Design

- HMI recommendation

System Validation

- Total system volume more than 99% accurate
  - Error validated by weight (+/- 0.2 lbs)
- 99% accuracy for chemical volume above 8 gallons



Materials Consumed

Actual Development Costs Incurred			
Prototype AutoBatch™ Automated Mixing System Skid			
COMPONENT	**UNITS**	**PRICE/UNIT**	**TOTAL COST**
Banjo Sprayer Fittings	1	$220.79	$220.79
PVC Test Stand Hardware	1	$35.00	$35.00
Venturi	1	$63.29	$63.29
Venturi Bypass	1	$84.06	$84.06
Check Valves	3	$11.68	$35.04
Hose	50	$1.76	$88.00
Hardware Shipping	1	$15.28	$15.28
Hardware Shipping	1	$35.93	$35.93
3 Phase 50amp Power Cord	2	$163.15	$326.30
12 Volt Battery Power Supply	1	$150.00	$150.00
Gasoline	1	$8.00	$8.00
R&D Labor	1120	$10.00	~
10hp Westinghouse Electric Motor	1	~	~
2" Ace Pump	1	~	~
5.5hp Gas Engine with 2" Pump	1	~	~
2" Electric Ball Valves	3	~	~
2" M100 Raven Flowmeter	1	~	~
1 1/2" P60 Raven Flowmeter	1	~	~
Microcontroller & RSLogix Software	1	~	~
Solenoid CIP Valve	1	~	~
Wiring Harnesses	8	~	~
User Interface	1	~	~
Platform Skid	1	~	~
IBC	4	~	~
Total Development Costs			**$1,061.69**

AutoBatch™ Projected Cost

Product Cost Comparison

Manual Mixing System Assembly

COMPONENT	UNITS	PRICE/UNIT	TOTAL COST
35ga Inductor	1	$400.00	$400.00
Primary Pump	1	$600.00	$600.00
Primary Gas Engine	1	$1,200.00	$1,200.00
Transfer Pump	1	$800.00	$800.00
2" Valves	2	$40.00	$80.00
Metering Device	1	$200.00	$200.00
Battery	1	$100.00	$100.00
PVC Fittings	1	$150.00	$150.00
Platform Skid	1	$150.00	$150.00
Assembly Labor	15	$12.00	$180.00
Hose	75	$2.50	$187.50
IBC	4	$0.00	$0.00
Total Unit Cost			**$4,047.50**
System Markup	50%	$2,023.75	$2,023.75
Projected Selling Price			**$6,071.25**

Proposed AutoBatch™ Automated Mixing System Skid

COMPONENT	UNITS	PRICE/UNIT	TOTAL COST
35ga Inductor	1	$400.00	$400.00
Primary Pump	1	$600.00	$600.00
Primary Gas Engine	1	$1,200.00	$1,200.00
Venturi w/ Bypass	1	$175.00	$175.00
3" Electric Ball Valve	1	$275.00	$275.00
3" Electro-Magnetic Flow Meters	1	$350.00	$350.00
Battery	1	$100.00	$100.00
PVC Fittings	1	$150.00	$150.00
Platform Skid	1	$150.00	$150.00
Manufacturing & Assembly Labor	15	$30.00	$450.00
Hose	50	$2.50	$125.00
IBC	4	$0.00	$0.00
1" Electric Ball Valve	4	$200.00	$800.00
1" Electro-Magnetic Flow Meters	4	$300.00	$1,200.00
Solenoid CIP Valve	4	$100.00	$400.00
Wiring Harnesses	15	$20.00	$300.00
Electrical Box / Protection	1	$100.00	$100.00
Controller (PLC)	1	$500.00	$500.00
Human Interface	1	$1,500.00	$1,500.00
Total Unit Cost			**$8,775.00**
Software Development & Rights	5	$500.00	$2,500.00
System Profit Margin	150%	$13,162.50	$13,162.50
Projected Selling Price			**$24,437.50**

Daily Cost Reduction

Daily Return Comparison for Commerical Applicator			
Standard Chemical Shuttle System		**Proposed AutoBatch™ Automated Mixing System Skid**	
Number of acres sprayed per day:	1500	Number of acres sprayed per day:	1500
Number of acres sprayed per hour:	150	Number of acres sprayed per hour:	150
Size of sprayer tank: (ga)	1200	Size of sprayer tank (ga)	1200
Number of batch loads per day:	12.5	Number of tanks filled per day:	12.5
Average time per tank fill: (min)	15	Average time per tank fill (min)	7
Daily minutes spent filling sprayer:	188	Minutes spent filling sprayer	88
Number of daily labor hours required: (spray + fill)	13.13	Number of daily labor hours required: (spray + fill)	11.46
Potential number of acres gained per day:	0	Potential number of acres gained per day:	250.0
Revenue generated per acre:	$5.00	Revenue generated per acre:	$5.00
Potential daily revenue increase:	$0.00	Potential daily revenue increase:	$1,250.00
Daily cost of labor required to mix batches: ($12/hr)	$157.50	Daily cost of labor required to mix batches:	0
Daily cost of operator: ($20/hr)	$262.50	Daily cost of operator: ($20/hr)	$229.17
Daily cost of machine operation: ($80/hr)	$1,050.00	Daily cost of machine operation: ($80/hr)	$916.67
		Daily labor and machine savings:	$324.17
		Daily fuel savings: (10gph) ($4/ga)	$50.00
Daily cost of Manual System:	**$1,470.00**	**Daily cost of Automated System:**	**$1,145.83**
AutoBatch™ Daily Return on Investment:		**$1,624.17**	
Potential Annual Return on Investment		**$33,817**	
Payback Period (Years)		**0.7**	

Daily Cost Reduction

Daily Return Comparison for Grain Producer			
Standard Chemical Shuttle System		**Proposed AutoBatch™ Automated Mixing System Skid**	
Number of acres sprayed per day:	1000	Number of acres sprayed per day:	1000
Number of acres sprayed per hour:	100	Number of acres sprayed per hour:	100
Size of sprayer tank: (ga)	1000	Size of sprayer tank (ga)	1000
Number of batch loads per day:	10.0	Number of tanks filled per day:	10.0
Average time per tank fill: (min)	15	Average time per tank fill (min)	7
Daily minutes spent filling sprayer:	150	Minutes spent filling sprayer	70
Number of daily labor hours required: (spray + fill)	12.50	Number of daily labor hours required: (spray + fill)	11.17
Potential number of acres gained per day:	0	Potential number of acres gained per day:	133.3
Revenue generated per acre:	$5.00	Revenue generated per acre:	$5.00
Potential daily revenue increase:	$0.00	Potential daily revenue increase:	NONE
Daily cost of labor required to mix batches: ($12/hr)	$150.00	Daily cost of labor required to mix batches:	0
Daily cost of operator: ($20/hr)	$250.00	Daily cost of operator: ($20/hr)	$223.33
Daily cost of machine operation: ($80/hr)	$1,000.00	Daily cost of machine operation: ($80/hr)	$893.33
		Daily labor and machine savings:	$283.33
		Daily fuel savings: (10gph) ($4/ga)	$40.00
Daily cost of Manual System:	**$1,400.00**	**Daily cost of Automated System:**	**$1,116.67**
AutoBatch™ Daily Return on Investment:		**$323.33**	
Potential Annual Return on Investment		**$5,283**	
Payback Period (Years)		**4.7**	

AutoBatch™ Project Conclusions

- Expandable for multiple chemical usage
- Customized algorithm and simple interface
- Innovative clean in place system
- Increased process repeatability and reduced human error

- **99% chemical injection accuracy!**

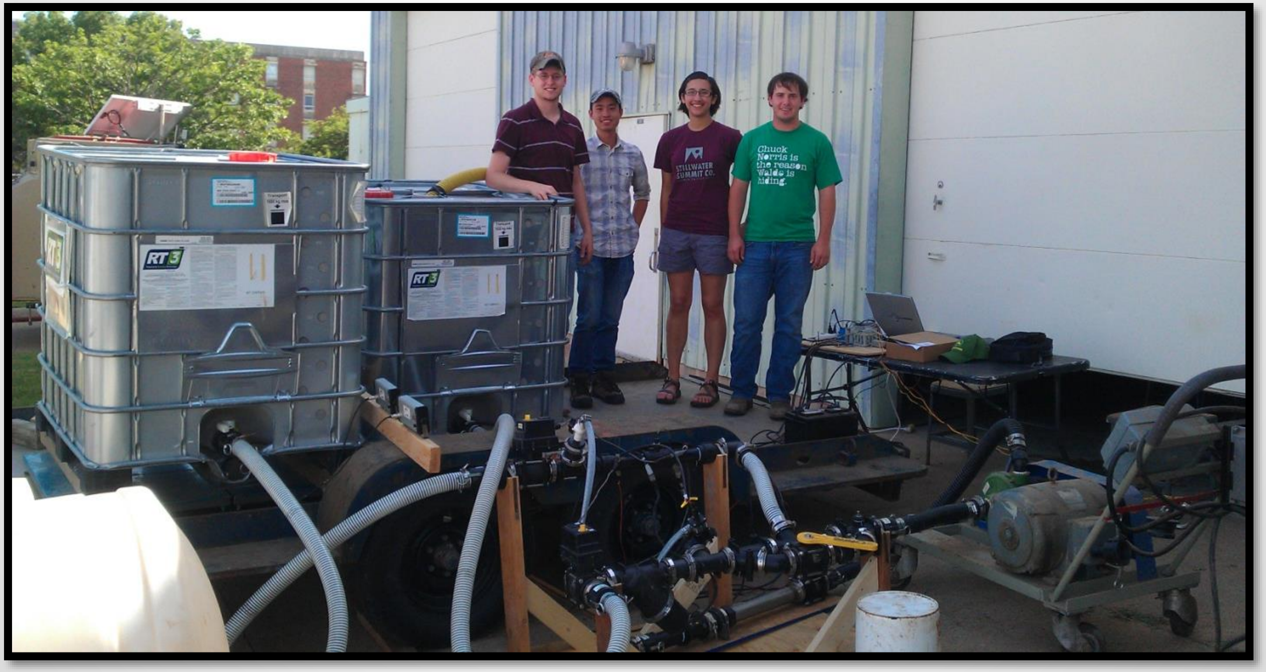
- **Less tendering time, and more field time!**

Acknowledgements

- Microfirm, Inc.
  - Mr. Kent Dieball
  - Dr. Marvin Stone
- Area Producers
  - Steinert Farms
- Agricultural Econ. Team
- Faculty & Staff
  - Dr. Paul Weckler
  - Dr. Randy Taylor
  - Dr. Dan Storm
  - Dr. Jason Vogel
  - Dr. Ning Wang
  - Dr. Glenn Brown
  - Dr. Joe Armstrong
  - Dr. Curtis Thompson
  - Dr. Jeff Edwards
  - Mr. Wayne Kiner

Join us for Demonstration

- BAE Lab



Automated Chemical Mixing System

N_2 Line Solutions

Collin Boettcher

Scott Clark

Eric Lam

Meredith Shiflet

Fall Semester Report

December 9, 2011

Table of Contents

Mission Statement

N_2 Line Solutions focuses on providing reliable chemical mixing systems for the application industry. We offer our customers pristine quality products with the latest technological advancements in a simplistic fashion, at an affordable price.

Background

Microfirm, Inc. is a company that specializes in electronics, automation, and sensing for the agricultural industry. Microfirm's owner, Mr. Kent Dieball, with the assistance of employee, Dr. Marvin Stone, approached N_2 Line Solutions with an idea of an automated chemical mixing system for large-scale agricultural applicators. Today, large chemical applicators can easily cover over 1,000 acres each day and may use several hundred quarts of several different products. Stopping to refill the spray rig with chemicals is one of the biggest burdens to the industry. Reducing the time necessary to refill will help producers and applicators to minimize their idle time and allow them to get more done each day.

Microfirm's goal is to produce an automated chemical mixing system that provides accurately mixed chemical batches while reducing spillage and exposure to the operator. Microfirm wants a system that accurately meters chemical and provides customized input sequencing. Microfirm hopes to be able to take this project further by making it a communicate with the spray applicator in the future.

Problem Statement

Commercial chemical applicators can spray hundreds of acres daily with ease, but some can spend over twenty-five percent of their days mixing chemicals and filling their solution tanks. N_2 Line Solutions has partnered with Microfirm, Inc. to develop an automated chemical mixing system that would alleviate the time spent mixing chemicals and help reduce the risk of human exposure. This automated fill system must interface with all major manufacturers, be user friendly, provide accurately mix chemical loads, record and summarize the dosage calculations, and be cost efficient for the end user.

Figure 1. Commercial spray rig.

Statement of Work

Microfirm, Inc. expects N_2 Line Solutions to devise an automated chemical mixing and dispatch platform to be used in conjunction with a nurse trailer or filling rig. The automated system will meter a series of chemicals from the inputs entered in the electronic user interface on the system, deliver the chemical to the solution line filling the sprayer, and rinse the system to avoid contamination. The system will also have the capability to incorporate granular products via an eductor. This platform should allow the user to create tank mixes with little exposure and also change the chemicals quickly with little spillage. The team will determine whether it is best to utilize a self-contained, on-board platform pump and power supply, or utilize an existing sprayer-mounted pump. N_2 Line Solutions will conduct most of the testing and design work in the Biosystems Lab and will have an automated system to meter chemical dosages accurately in May of 2012.

Scope of Project

N_2 Line Solutions must submit the following at the end of the Fall 2011 semester.

- Team Overview
- Mission Statement
- Problem Statement
- Statement of Work
- Industry Analysis
- Competitive Research
- Technical Research
- Testing and Experimental Data
- Design Concepts
- Proposed Budget and Business Plan

By the semester's completion, N_2 Line Solutions will provide a conceptual design and report the results assessed in any prototype testing. The team will also propose component technical specifications, product plans, and an enterprise budget and comprehensive marketing strategy.

This project focuses on producing an automated chemical mixing platform. Not only should the system allow for accurately measured chemicals to be injected into the streamline of the base solution, the system should allow for manual chemical addition via an eductor. This system will reduce chemical exposure and spillage as well as help users monitor their chemical batches.

Location

The product design will be completed by N_2 Line Solutions for Mircofirm, Inc. as part of the Biosystems Engineering Senior Design capstone program. The work will be conducted in the Biosystems Engineering lab shop on the Oklahoma State University campus in Stillwater, OK.

Additionally, the team will do a large part of their testing at the Biosystems annex on the Agronomy Farm due to the number of projects in progress and limited space at the BAE shop. The team will also utilize the Biosystems computer lab for research and data analysis. Necessary fabrication will be completed in the shop or by Wayne Kiner's staff as needed.

Schedule of Work

N_2 Line Solutions will provide a conceptual draft of the proposed product to Microfirm at the acceptance meeting in December. Requirements and deadlines for the fall semester are shown in table 1. The team will complete as much fluid flow and metering testing as possible in order to provide a better proposal to the client. The primary prototype construction and testing will be carried out in the spring semester.

Table 1. Course deliverables for the fall semester.

Fall Semester Requirements	
Deliverable	**Due Date**
Team Leader	Sep 09
Team Name	Sep 12
Team Logo	Sep 19
Mission Statement	Sep 28
Problem Statement	Sep 30
Research Outline	Oct 03
Test Plans	Oct 17
Project Research Report	Oct 21
Statement of Work	Oct 28
Schedule of Work	Oct 31
Final Report Submission	Dec 08
Final Presentation	Dec 08

1) Reduce the time required to re-fill the sprayer tank.
2) Prevent chemical spillage.
3) Assure ingredients are added in the correct order and amount.
4) Minimize exposure of operators to agricultural chemicals.
5) Provide an economical automated system to agricultural chemical applicators.
6) Utilize the pump existing on the sprayer to draw water and chemicals into the sprayer during refill.**
7) Target a re-fill to be completed within 3 minutes for 1000 gallons.
8) Utilize "Off-the-shelf" valves, metering devices and control components.
9) Provide an inductor and tank in the design for adding dry flowable powders and liquids.
10) Provide a rinse function to assure lines can be rinsed as a part of the last tank load of a field.**
11) Adjuvants and other tank mix components (AMS for example) must be added to the mix in a certain order to have effectiveness and/or prevent mixing problems.
12) Provide a central operator interface to allow entering formula amounts for each ingredient and provision for setting the total amount of mix to be loaded.
13) Provide a single "Start" button to run the process to completion and an interrupt button to allow an operator to stop the fill process. Some provision is needed to continue after stopping.
14) Reasonable assurance that the system meets any applicable EPA and or OSHA requirements.
15) Reasonable assurance that the design does not infringe on any known patents.
16) Identification of any competitive products.

Product Requirements and Deliverables

- **Mobile Batch Chemical Mock Unit**
  - **Reliable System to Fill 1200ga Solution Tank in 5 Minutes**
  - **4 chemical totes and 30ga Inductor**
  - **Off-the-Shelf Components**
- **Functional Batch Sequencing Algorithm**
  - **2-4% Product System Metering Error Accepted**

Automation and Instrumentation

N_2 Line Solutions

Platform Construction

N_2 Line Solutions

Activities and Tasks Timeline

N2LS-1.0: Task A

N2LS-2.0:

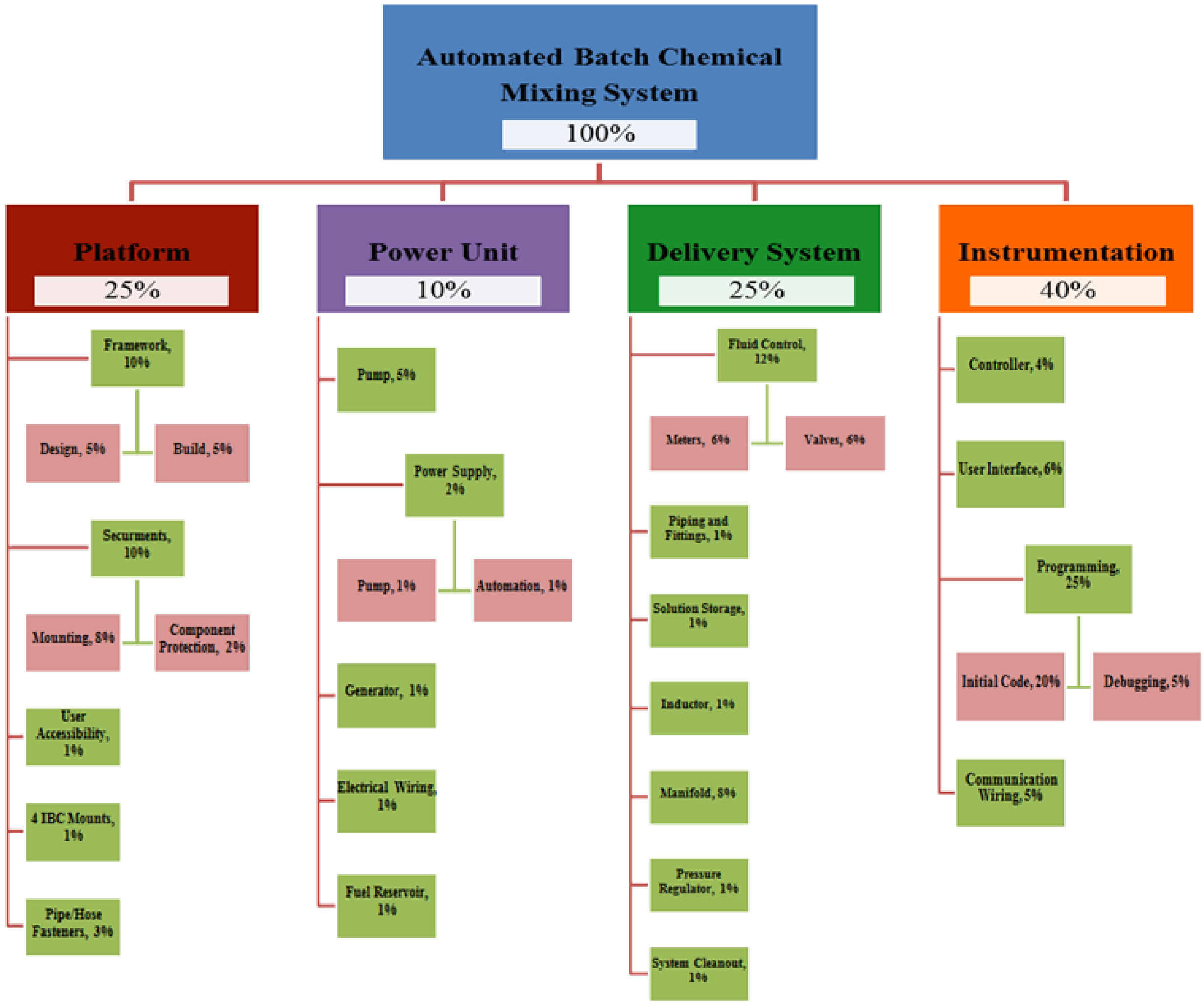
N2LS-3.0:

N2LS-4.0:

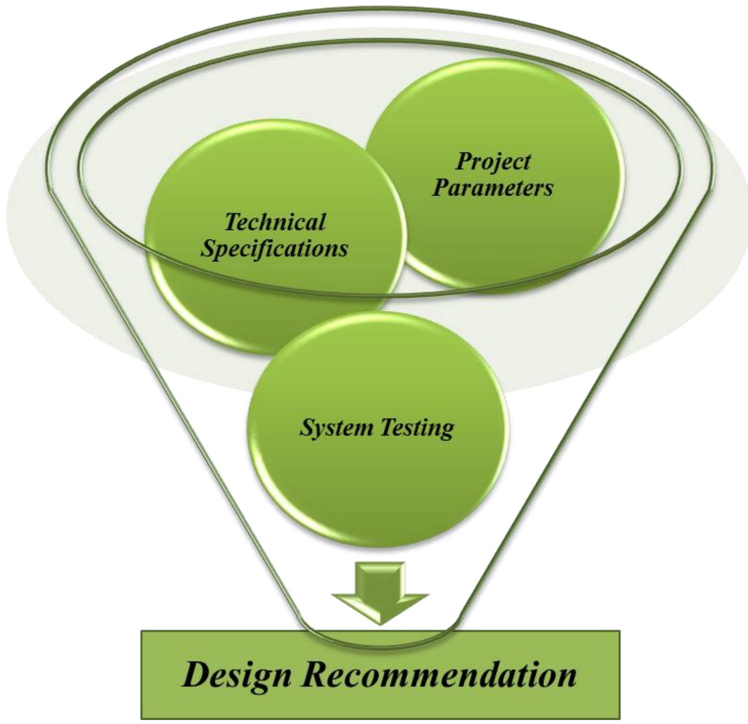
N2LS-5.0:

Work Breakdown Structure

Show As Appendix



December Expectations



Resources Needed

N_2 Line Solutions will utilize as many components and fittings available to them through the client and the Biosystems and Agricultural Engineering department as possible for testing. However, the final product design will be based on what the team determines is needed, not what is necessarily readily available. Microfirm will make the final determination of what components they would like the team to buy for the project. Outside of the components and workspace needed, the team will also need software for programming the controller and developing the interface. The team may also need to designate a specific laptop for use with this project as must of the large-scale testing will be done at the BAE Annex.

Acceptance Criterion

Microfirm's approval and acceptance of the suggested product is N_2 Line Solutions' utmost concern. Microfirm has provided initial constraints and requests to guide the project, but ultimately N_2 Line Solutions will be testing components and constructing this system based on research and testing results. The product must be functional in the regard that it meters chemical accurately using a programmable logic controller, as determined by the entry at the interface. To assist in accurate metering and contamination prevention, the system must have the capability to be flushed out and adhere to EPA and OSCHA requirements. Additionally, the product must have the capacity to fill an 800-1200 gallon spray rig in less than five minutes. The assembly, or mobile platform, must be easily transported using a standard forklift and should be designed to be incorporated into a variety of applications.

Targeted Customer

A batch chemical mixing system platform is designed for customers operating spray rigs with 90 or 120 foot boom widths and 800-1200 gallon solution tanks. These rigs are typically utilized by large producers or commercial applicators that need to cover a lot of ground in a short amount of time. The machinery has the capability to meet applicators' needs, but the time required to mix chemicals and refill the sprayer is usually around 12-15 minutes and is detrimental to the operation's production. N_2 Line Solutions' customer is Microfirm and the end user's logistical needs may include, but are not limited to the following three scenarios:

Figure 2. Tank, batch mix, and sprayer transport trailers.
[1]

[1] JD Skiles Company. Retrieved October 19, 2011 from JD Skiles: http://www.jdskiles.com/pitstopsprayertrailer.html

Figure 3. Nurse trailers with batch mix area.

Figure 4. Short utility trailers for hauling platform separately when used in conjunction with a bulk fill tanker or mobile field tank.

As more and more producers turn to no-till and minimum tillage instead of conventional tillage, the number of acres requiring herbicides sprayed on them increases exponentially. With $4-$5 custom applicator fees per acre, large farmers are beginning to purchase their own sprayer to spray their own crops. Furthermore, commercial applicators are gaining more clients or acres, and are purchasing larger spray rigs and looking for avenues to increase their efficiency and their overall number of acres sprayed daily. According to Farm Industry News, "Hagie Manufacturing has already booked and sold all of this year's sprayers that they can produce." Other major manufactures such as AGCO, John Deere, New Holland, and Case IH are also producing and shipping sprayers at rapid rates. As the number of acres sprayed and number of sprayers continues to increase, the market for a fast and efficient intermediate chemical shuttle will grow dramatically.

Industry Analysis

Providing the targeted customer with what they need and want is important to the success of any product. Most any business focuses on what the buyer wants, but this product is somewhat unique. N_2 Line Solutions has acknowledged the concerns of the end user and desires to produce a product that will be used by producers right away, but the team must also create a product for its client, Microfirm, that is on the cutting edge of technology in the industry. This poses a challenge for the team as most buyers are looking for a simple and straightforward mechanical process while Microfirm is looking at the direction of this industry. Technology changes continually and has not always been welcomed at first, but just as yield monitors made their way into combines and autosteer systems made their way into all farm equipment; functional, automated chemical shuttles are likely to take off as well.

The batch mix chemical mixing platform should be applicable for customers today, but provide an avenue for chemical shuttles into the future. Although the economy has been suffering as of late, the agricultural commodity prices have remained attractive and input prices such as fuel have begun to decrease. These factors will help N_2 Line Solutions market and sell a more expensive chemical platform, particularly if it saves the applicator time. The development of this product should take one year and the product should be available to the market in the fall of 2012. However, testing modification of the automation of the system should continue for two years to better adapt the program. With the help of other manufactures, Microfirm should ultimately be able to assemble a platform that an applicator can pull up to, mix chemicals, fill the sprayer, and back away without ever leaving the operator's station. No expansion plan should be needed until the product success and market viability has been proven and the profitability levels have been maintained.

Regulations & Standards

The main source of regulation within the chemical industry is provided through the United States Environmental Protection Agency (EPA). Comprehensive data is available through the EPA for each state's specific regulations. There are two main federal laws governing the distribution, use, and disposal of pesticides: the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). Many of these regulations overlap and interact to provide adequate regulation for the pesticide industry.

The FIFRA mandates that all products be licensed and registered with the U.S. EPA before production and distribution. This legislation also standardizes labeling, packaging and disposal procedures while providing for situational emergency use which may violate standard procedures. Special application exceptions may be granted when there is a risk of substantial financial loss or harm to endangered species or other negative environmental impacts. The EPA also has authority under FIRFA to remove a products approval at any time and gives proper procedures for appeal. The EPA has issued a Label Review Manual (LRM) which aids in the interpretation and creation of chemical labels. Deviations from the standards presented in the LRM are considered violations of FIRFA. The LRM details every aspect of pesticide labeling process including but not limited to ingredient listing, hazard warnings, personal safety and handling, directions for use and manufacturer contact.

The FFDCA mandates the safety and tolerances of pesticide use as it pertains to food or livestock production. The procedure for establishing and regulating application tolerances and standards mandates that all levels must never reach a level where they are likely to cause harm or loss of life. Residual pesticide tolerances within food products are further regulated by the Food and Drug Administration; FFDCA specifically focuses on the production process. Additional legislation includes the Pesticide Registration Improvement Act (PRIA) of 2003 which further regulates the registration of chemicals into three distinct categories.

Regarding storage and disposal of pesticides, FIRFA as well as the Resource Conservation and Recovery Act (RCRA) ensure responsible management of chemicals. Most states have instituted programs specifically for agricultural producers for proper chemical disposal. State extension resources are available through the EPA Pesticide Storage Resources section. The Clean Water Act also regulated pesticide tolerances and how they relate to water quality. This greatly impacts where, how and under what conditions a chemical may be applied in order to minimize environmental impacts.

Publications

Resources for chemical applicators are quite varied and specific to location. The American Society of Professional Pesticide Applicators (ASPPA) provides national and state opportunities for education, networking, and resources. Online training and study classes are available for certification and additional development. The Soil and Water Conservation Society (SWCS) is a national organization that provides training and information to improve water quality and conservation practices. Information on the certification of training to be a legal chemical applicator are available through the EPA. Most agricultural based universities have extension offices directed towards serving the public with technical assistance. The Oklahoma State Extension office offers training, seminars, as well as general information readily available to the public.

One of the biggest scenes for new agricultural products is farm shows and trade show conventions. These shows get new products in front of potential customers and allow them to see, and often use the product. N_2 Line Solutions recommends that Microfirm take advantage of these shows to test the market for this type of product and to get feedback on potential areas of concern. Another area that sells product to this type of targeted customer is literature, pamphlets, magazines, and websites. These sources promote the product by education and identification of the product. The information should portray how the product will fulfill the current needs of the customer while increasing his productivity and bottom line.

Customer and Buyer Research

N_2 Line Solutions is going to design an automated chemical shuttle on a platform. This will allow the user to easily transport it and operate the entire system in a close proximity. An automated system will be more beneficial than a traditional system because it will allow for multiple activities to be occurring at the same time with one operator. Whereas in the past, it might have taken two, or even three workers to do the same job in equal or more time. Not only will this system reduce the labor involved and the time invested, it will protect the users as well. An automated setup would allow the operator to push a button to switch tanks or open a valve instead of physically moving a pump or disconnecting a hose as done previously. These equipment switches spill chemical all over the work area and the user. Some chemicals, such as

Paraquat or "Gramoxone", are toxic to humans and have no identified antidote. Upgrading to an automated chemical handling system could save lives!

As opposed to similar mechanical systems on the market, this platform would come pre-assembled and will be versatile in order to encompass the needs of a Kansas wheat farmer, a Texas cotton farmer or an Iowa corn farmer. Minor changes to the assembly will allow each user to customize the platform to his or her needs, but eliminates the time and knowledge required to build an intricate system from scratch. Using an automated chemical system can help save several minutes at each fill up, and up to 12 hours over the course of a week! Applicators often have a narrow window of time to get chemicals applied due to weather or agronomic conditions. Reducing the time required to complete the task will allow them to do more than ever before in the same narrow windows presented to them. This system could save the producer thousands of dollars by allowing applicators to get more done each day or by getting a field completed sooner before a storm arrives to wash away the chemical. Helping applicators to reduce their fields that have to be re-sprayed also helps protect the environment. Additionally, this product could help reduce the footprint of spray rigs if an applicator doesn't have to redo a job because his batch wasn't mixed correctly the first time. If a producer has considered increasing his boom width from 90 feet to 120 feet, but is concerned that his fields are not big enough for 120 foot booms, this may be the solution! This system could offset the difference between the boom sizes without ever trading equipment.

Competitive Product Evaluation

N_2 Line Solutions is developing an automated process to assist farmers with mixing chemicals to fill a sprayer. The system will also allow the user to manually add or slurry chemical products. The system will decrease the overall amount of time it takes to fill the sprayer with chemical and the base solution. The versatility of this product will allow the system to be used however and wherever it is most convenient to the user. The industry depicts a need for a faster way to load chemicals, but

Figure 5. The JD Skiles pit-stop platform uses a volumetric measuring system.

research shows there are very few chemical mixing systems on the market. Some manufacturers, such as JD Skiles of Atwood, KS, have devised mechanical systems that work very well but are still tedious work for the operator(s) to maintain and control.

The Kahler system automates chemical flow using an interface, but does not contain the whole process from chemical mixing to delivery of the batch to the sprayer. Most of the Kahler systems available are designed for operation within an enclosed environment and are not robust enough to be used in a mobile application. Additionally, this system is setup for use in a warehouse with a120 volt power supply.

Figure 6. The Kahler system could be used within a system to automate chemical flow.

Another product on the market worth mentioning is the LoadCommand system sold by John Deere Company. The system houses a pump on the sprayer unique to the system as well as a specific hose hookup location at the front of the sprayer. These systems also require a tender arm to be mounted on the trailer or tank delivering the solution. Once the operator hooks the arm to the sprayer, the operator can return to the cab of the unit and back away from the arm after the solution tank has been filled as the connection unhooks itself.

Figure 7. The John Deere tender arm and front hookup.

One of the disadvantages of the LoadCommand system is that it is only good for pre-mixed solutions. However, the system can deliver up to 400 gallons per minutes, so mixing chemicals with the solution will cause foaming upon loading the mix into the sprayer. Thus, most users only use this setup when top-dressing, or applying liquid fertilizer on their crops where little or no other products are used. Additionally, each of the nurse trailers servicing the system must be equipped with the pricey tender arm and connection. Although N_2 Line Solutions likes entertaining the idea of having a system that can connect and unhook itself before and after the filling process, the team will not work on that aspect of the project. Instead, N_2 Line Solutions will concentrate on the automation of injecting at least one, and up to four chemical products into the flow of the base solution. The desired quantities of these products will be entered into a display on the platform. The interface will allow the user to sequence the chemical injections and provide a summary of the batch mix.

Technical Development

N_2 Line Solutions has contacted numerous applicators for feedback regarding an automated chemical system and chemical shuttles in general. The team also traveled to Matt and Adam Steinert's farm near Covington, OK to look at their current system and visit with them about the requirements of an automated design. The Steinerts graduated from Biosystems Engineering and now farm and run a commercial application business. They spray thousands of acres annually and may handle thirty or more products daily. Some of the main concerns the Steinerts had of this type of system were:

1) Protecting the system from corrosion due to moisture, chemicals, and physical damage.
2) Developing an automated volumetric system to visually check the system.
3) Producing a high enough flow rate with the sprayer's pump to achieve the load time goal.
4) Creating a vacuum for pulling product or pushing out the solution during cleanout.

Matt also suggested the team consider utilizing a hydraulic pump to allow for variable flow rates to be achieved. For instance, this would allow a user to treat the base water solution with ammonium sulfate at a slow rate initially while the chemical batch is entered into the system and help prevent the sprayer form being filled with solution before all the chemicals are added.

Figure 8. Matt Steinert is a commercial applicator.

Some chemicals may need to be slurried in the eductor and would therefore take more time to mix than other tank batches. Matt also stated that his electronic flow meters are replaced about every 20 months because the seals wear out or the calibration begins to distort and cause inaccuracy due to high viscosity fluids building up in the flow meters. He has pulled some of the electrical components off of his system and gone back to a more manual process for reliability.

Although potential customers have made it clear that flow meters wear out and electrical systems don't typically last well outdoors, N_2 Line Solutions can cope with these

Figure 9. Visiting a producer to learn about the industry.

problems. By utilizing "off-the-shelf" components that are regularly available, as requested by Microfirm, the design team can accept a shorter life span on components as users will be able to easily attain replacements. Furthermore, the design team will emphasize robust electrical components for the automation of the chemical mixing. Selecting durable components and enclosing them when possible will help to reduce physical contact, aid in preventing exposure from chemical spills, and assist in preserving the components as they will be secluded from the elements.

Chemical Selection

N_2 Line Solutions needed to formulate a list of chemicals to consider for the algorithm and coding of the mixing system. Since Microfirm wants to focus on the Midwest region with an initial emphasis on wheat production, the team compiled a list of chemicals most commonly used by producers in Texas, Oklahoma and Kansas. Dr. Joe Armstrong, Plant and Soil Sciences professor at Oklahoma State, and Dr. Curtis Thompson, professor of Agronomy at Kansas State provided feedback and helped N_2 Line Solutions develop the following list of herbicides, additives, and surfactants. This chemical list will help the design team determine the flow rates needed by the system and assist in sizing components. Additionally, these chemicals will allow the team to compare fluid density extremes to determine metering accuracy variation.

1) ***2,4-D Amine***
2) ***MCPA***
3) **Axial XL**
4) **Clarity (soluble)**
5) **Finesse (dry)**
6) **Olympus (dry)**
7) **Ammonium Sulfate (liquid)**
8) **Ammonium Sulfate (dry)**
9) **ChemSurf or Squire (Non-Ionic Surfactant)**
10) **Glyphosate**
11) **Dicamba**
12) **Paraquat**

13) **Valor**

14) **Brash/Weedmaster = 2,4-D Amine + Dicamba**

15) **Gramoxone**

16) **Harmony Extra**

17) **Express**

Client Resources and Suppliers

A successful company requires disciplined management and experienced employees. The management team should have experience with marketing and sales as well as industry analysis. The designers and employees assembling the platform should have ties to agricultural applications, sprayers, and chemicals. The engineers must be able to communicate with the end user of the product and comprehend his or her needs and suggestions.

The product line falls under chemical mixing, nurse trailers, and spray rigs. The product is encompassed by a platform that handles all of the chemical mixing and interaction from the time it leaves a bulk container to the time it reaches the spray rig.

The manufacturing capacity for this product does not need to be large in the early goings as it will take some time to develop a product that has great functionality and is accepted by users. However, a manufacturing facility that can handle the quantity increase as the product becomes more highly marketed is important for the financial stability of the company. Although a large facility will hurt the company in the beginning because it will influence the cost associated with the product, it will increase manufacturability and the process as the volume of the product increases. The marketing personnel should provide an expected plan for the quantity of products to be produced over a two, five, and ten year span.

N_2 Line Solutions suppliers are going to be in the agricultural, electrical, plumping, plastic, and chemical industries. Until prototyping has been completed, the final supplier list will be unknown.

N_2 Line Solutions will need a provider for Drisco pvc pipe, Banjo fittings and connectors, as well as a supplier for the user interface, microcontroller, electrical sensors, electrical valves, and connectors. Additionally, the team will investigate potential power supplies and pumps.

Industrial Bulk Containers (IBCs), solution storage tanks, and an inductor will also be needed. The IBCs will be borrowed for the duration of the project from Matt Steinert and the storage tanks will be borrowed from Dr. Randy Taylor and the Biosystems and Agricultural Engineering lab. An inductor will be purchased from a supplier.

Prototype Testing

N_2 Line Solutions must produce an automated chemical mixing platform that meters chemical accurately. Without accuracy, there will be no use for the product. The main emphasis for preliminary testing we will be chemical metering accuracy with varying fluid viscosity, complete product addition and mixture of the chemicals in the system, cleanout of the mixing platform system, and the overall speed of the mixing system. For N2 Line Solutions to successfully design and build a portable chemical mixing unit, the team must first construct a simple test stand to determine the consistent accuracy of various flow meters. Testing will consider electrical flow meters similar to the one shown in figure 1, as well as volumetric measuring devices with electrical monitoring. During testing, the team will find the corresponding calibration curves with the flow meters as to incorporate that adjustment into the coding of the software if necessary.

Figure 10. Turbines electrical flow meter.

Once the team has determined the best avenue for metering the chemical products, it will be necessary to install additional components onto the prototype in order to test the mixing concept of the platform. The team will need two plastic intermediate bulk containers to assess the logistics of transporting the chemical from the storage container into the line transporting the base solution. The team will also need a large water source and tank to provide the base water solution. A pump to transport the water solution to the mock mixing platform will aid in simulating the flow.

Once the mock platform is constructed, the programming code will need to be written to meter a desired amount of product 1 and product 2 as checked by volumetric measurement. Once the programming has been verified, the system will need to incorporate the correctly measured chemical into the stream of solution in the proper sequencing as requested. This will serve as an initial test and allow the team to debug the electrical system, including all hardware and software. Once the system is running properly under the initial criterion, we can add more products and begin to design the user interface.

The ISO 11783 Virtual Terminal protocol was created by Dr. Stone in order to bridge the communications gap between equipment produced by all manufacturers. The idea to use virtual terminals (VTs) allows the "operator to switch to see either a drill or sprayer" produced by two different manufacturers on the same monitor. This system was created in 2000 and has since been integrated with modern precision agriculture equipment and supported by equipment manufacturers such as AGCO, John Deere, and Case IH. This protocol formalized to the ISOBUS Standard 11783 in 2006.

It is beyond the scope of our project to program the platform with ISOBUS, but utilizing a VT system will allow our client to pursue this in the future if desired. We have the option to use a simpler software platform for our prototype, but will use the system that complements our customer's needs. Potential microcontrollers would include the Parallax Stamp or the Arduino.

N_2 Line Solutions has found no supporting evidence that a manufacturer produces a fast and reliable pump contained on the sprayer. After meeting with one of the largest chemical applicators in the area, N_2 Line Solutions confirmed these suspicions. The team will pursue the idea of an on-platform motor and solution pump. Research will be done on hydraulic pumps to meter the proper amount of solution to the spray rig. Although hydraulic pumps will create an more complicated and expensive eliminate to the system, a hydraulic pump would allow for more accurate flow rates to be realized. Traditional gas pumps and John Blue pumps are manually throttled to change the flowrate of fluid going through the system. A hydraulic pump accompanied by a microcontroller would allow the user to set and attain more precise flow rates through pulse width modulation of the pump or valves for flow control. This would allow the operator to set a flow rate that the controller would translate to a frequency of action for the unit. The Arduino microcontroller would be ideal for this purpose as a pulse width modulation library can be programed and customized on the controller. It also has a wider range of frequency operation than the Parallax. All other operations, such as flow metering and volume measurements, can also easily be monitored by the Arduino.

For testing, we will need multiple electric flow meters, volumetric meters (tanks and electrical metering floats), multiple tanks, miscellaneous fittings and connectors, pumps, solenoid valves, power supply gas motor, hydraulic pump and components to drive and maintain the contained system, an Arduino, and a user interface. We are interested in a volumetric measuring and monitoring system such as the one shown below, but must determine the best way to automate the tanks robustly.

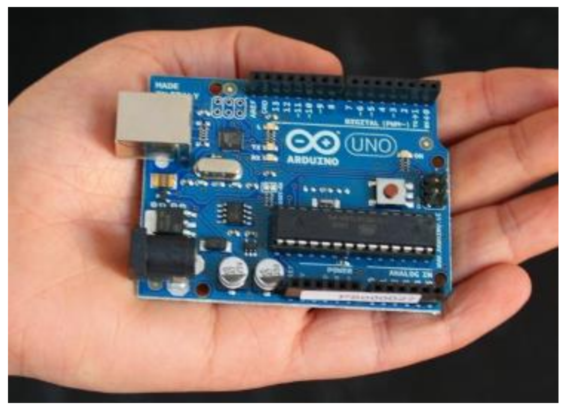


Figure 11. An Arduino microcontroller.

N_2 Line Solutions will need to develop a prototype microcontroller. An Arduino microcontroller has an 8-bit Atmel AVR processor and on-board I/O support. The programming takes place on a personal computer and then flashed onto the Arduino controller through a USB adapter. The team expects the 14 I/O pins, 6 analog input pins, and 6 PWM pins to be sufficient for control of all sensors. The language used for the controller is very similar to C++, but with support for libraries. The Arduino is a popular prototyping board and there are preloaded libraries available online to experiment with during testing.

Component Selection

Microfirm presented N_2 Line Solutions with some component criterion to meet. Two of the most important were:

1) Selecting easily accessible components that are readily available.
2) Utilizing a programmable logic controller to communicate with the system.

Power Unit

N_2 Line Solutions considered several alternative pump types including positive displacement pumps, direct injection pumps, and centrifugal pumps. The team additionally compared electrical and gas engine power supplies. After researching positive displacement pumps and direct injection pumps used in chemigation, the team discovered neither would be applicable for the project at hand due to the low flow rates they produce. The first combination the team analyzed was a hydraulically driven centrifugal pump with an electrical power supply. This system was lucrative to the team for these reasons:

1) Most operation can be managed from the user interface. Once the generator has been started, the electrical motor’s speed will be constant and the user can make all other adjustments from the interface/controller.
2) The hydraulic motors can be adjusted to control the water or fertilizer solution, or the chemical product flow rate using the swoop valves from the controller.
3) This flow rate control eliminates the need for a primary system flow regulating valve and the team feels it will assist in providing a higher level of metering accuracy consistently.
4) This system will allow the user to turn off the secondary pump from the interface when not in use. Otherwise, the pump would often be left running between chemical addition and system cleanout.

The hydraulic system offers many features that would allow the team to provide the operator accessibility from the interface, but it comes at a price. An estimated system budget for the major components is shown in the following table.

Table 1. Hydraulic system cost estimate.

Cost Projection for Hydraulic System		
Component	**Size**	**Est. Cost**
Primary Centrifugal Pump	3" In/Out with 350 gpm	**$ 800**
Secondary Centrifugal Pump	2" In/Out with 75 gpm	**$ 600**
Primary Hydraulic Motor	8 gpm, 3600 rpm	**$ 500**
Secondary Hydraulic Motor	8 gpm, 3600 rpm	**$ 750**
Hydraulic Pump	2000 psi, 20 gpm	**$ 1,300**
Swoop Valves	8 gpm each	**$ 1,100**
Electrical Power Source	23 hp	**$ 2,000**
Gas Generator	17,135 Watts	**$ 3,000**
Hydraulic Hoses/Fittings		**$ 150.00**
Total Hydraulic Components Needed to Purchase:		**$ 10,200**

Since Microfirm is a small company that focuses on sensors, electronics, and programming; the team elected to eliminate the expensive hydraulic alternative. Acknowledging that cost reduction is a critical part of the project with Microfirm, the team continued to further investigate component resources and availability. N_2 Line Solutions met with Dr. Randy Taylor, Dr. Dan Storm, Wayne Kiner, and Dr. Marvin Stone to discuss the Biosystems resources available to the team. Dr. Storm allowed that he had several gas engines connected to various centrifugal pumps that the team could utilize for their testing. Additionally, Dr. Taylor and Mr. Kiner designated a bank of Banjo fittings and connectors that could be used for the project. Dr. Stone provided the team with several Raven flowmeters and wiring harnesses to use for project testing, and perhaps the final product.

Although the team elected to pursue a gas engine driven three inch centrifugal pump for the primary solution based on cost and pump availability; the team also recognized that the industry primarily uses this same pump configuration currently. Yet, the team will be utilizing an electric motor driven two inch centrifugal pump for testing. This three phase motor variable controls the pump and will allow the team to quickly test the system at varying flow rates.

Figure 12. Three inch Banjo centrifugal pump with 13hp Honda.

Figure 13. Primary system 2" centrifugal pump with 10hp electric motor.

Figure 14. Electric transfer pump.

Many users also use an electrical transfer pump regularly to pull chemical from totes into the inductor. The team wanted to utilize this same concept for the pump on the secondary system for the platform in order to maintain component familiarity and assist with integration in the marketplace. An electrical pump could be controlled from the controller at the interface easily, but it demands a large power supply estimated at 2000 watts. The team debated the use of an alternator driven from the primary pump's gas engine to recharge the system's battery. This idea was presented during a meeting with Microfirm. However, the client elected to utilize a second, smaller gas engine to drive a centrifugal pump to avoid the extra specialized component assembly. The disadvantages to this system are increased cost and manually starting and stopping the engine at the pump site, but it will allow the team to utilize Dr. Storm's engine and pumps for the project. Below is a Briggs and Stratton 5hp engine with a ___________ 100 gallon per minute pump.

Figure 15. Prototype secondary system engine and pump.

Programmable Logic Controllers

Programmable Logic Controllers (PLCs) are specialized for electromechanical processes and most contain a simple Human-Machine Interface (HMI) that have simple, small screens or Light Emitting Diode (LED) lights signaling the progress of the system. N_2 Line Solutions will develop an algorithm based on the components utilized and the specific chemical products used in the mixing process. The number of inputs and outputs will need to be determined before a controller can be selected. The algorithm will need to be programmed and flashed into the PLC prior to installation using a personal or laboratory computer. Constructing a specific algorithm for this system will allow the list of developed chemical products to be acknowledged by the controller. This list will may have specific fluid properties preloaded into the system that will help ensure each chemical is mixed accurately, but will also allow other unknown chemicals to be selected for mixing with an expected metering error. This allows for more robustness of the unit because it doesn't rely on being reprogramed frequently, but also limits the operator's metering exactness as the algorithm won't contain every chemical available on the market.

N_2 Line Solutions has considered several controllers including: Devilbliss, Allen Bradley, and ___ ______.

Dr. Stone provided the team with an Allen Bradley A and B……

The team determined the automation components and PLC requirements with Mr. Dieball at a specific meeting regarding the programming of the system.

Figure 16. A robust PLC with a digital screen.

The International Electrotechnical Commission (IEC) standard 61131-3 defines five programming languages for PLCs. These include Function Block Diagrams, Ladder Diagrams, Structured Texts, Instruction Lists, and Sequential Function Chart. Our group will pursue Function Block Diagrams and Ladder Diagrams for the language used in this product. N_2 Line Solutions must determine the specifications necessary for the product in order to mirror the PLC with those requirements because there are many types of PLC specialized platforms.

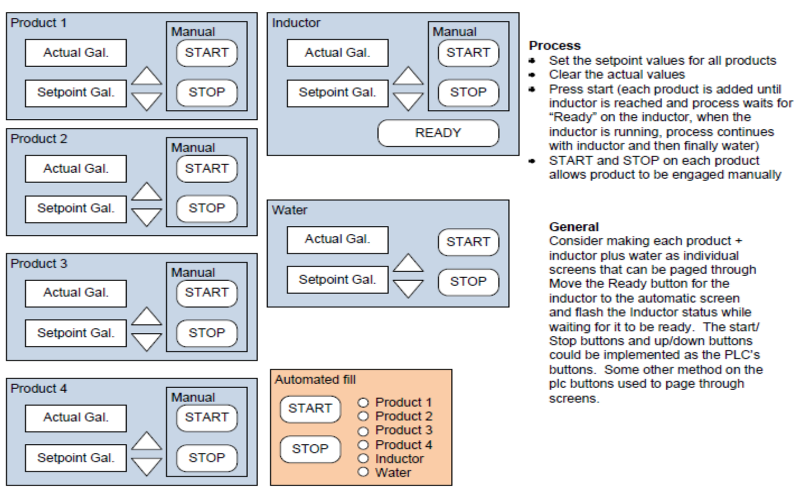


Figure 17. The interface.

Chemical Metering

Metering chemical is one of the most important aspects of this product. N_2 Line Solutions will consider two avenues to meter chemical:

1) Flowmeters
2) Volumetric measurement

Flowmeters

Three types of flowmeters have been researched: mechanical, pressure based, and mass flow.

Mechanical Flow Meters such as turbine flow meters are the most common type of metering device currently used by applicators. This flowmeter utilizes the axial revolving of a propeller to determine the flow of a fluid through it. Although it is reliable when used for the same application over and over, a problem is presented when fluids of different densities are used.

Pressure Based Meters, like Venturi meters, restrict the flow of a fluid and use pressure sensors to measure the differential pressure that flows across it. This differential has preset values programmed into the system that allow the meter to display the flow rate of the fluid. Pitot tubes utilize Bernoulli's equation to calculate dynamic pressure and fluid velocity. These are used commonly to measure wind speed for airplanes and high velocity fluids.

Mass Flow Meters work on the principle of inertial flow in order to gauge mass flow rate of a fluid. These types of sensors are not used as commonly as the mechanical and pressure meters, but they do offer an additional benefit over the other types of meters. Mass Flow Meters have a greater flexibility of fluids capable of measurement. This type of meter may need to be tested further in the application of a chemical batch system to see if it can reduce the error associated with measuring various fluids with fluctuating densities and viscosities.

Volumetric Measuring

Volumetric metering is the second type of measurement N_2 Line Solutions will consider. The advantage of this type of chemical measuring is that it provides a "peace of mind" for the operator because they can see exactly how much chemical is being mixed in the batch and double check their entries of the interface. The team will consider adding additional tanks for measuring each of the products as well as utilizing the eductor to measure the products.

There are several ways to automate and monitor fluid levels using a volumetric system. Ultra sonic sensors that emit waves down to the fluid and bounce back measure the distance of the fluid from the sensor as the tank is filled. Pre-programming the volume into the interface would allow the sensor to quantify a volume from the distance reading and shut the valve off once the appropriate level has been reached. A disadvantage to this type of sensor is the consistency of the surface of the chemical in the tank. If the chemical foams up, the sensor will read the volume inaccurately as it would if the chemical were sloshing or bubbling up in the tank.

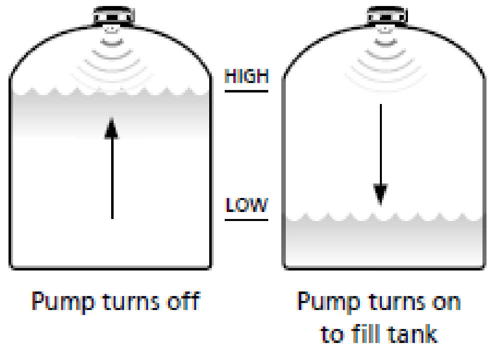


Figure 18. An ultra sonic sensor measures fluid flow and tank levels.

Another way to monitor the volume would be using a linear potentiometer. A calibration would be necessary to achieve the proper resistance in the potentiometer. As the fluid fills the tank, the potentiometer will rise with the fluid. If the operator requests twenty gallons of RoundUp, then the system will associate twenty gallons with the resistance value and height of instrument extension. Extensive strain measurement and resistance calculations relative to various fluid densities would be necessary to determine if a potentiometer would be accurate for all products.

Another type of measuring device N2 Line Solutions has explored is a float valve. Utilizing a float would be similar to a linear potentiometer in the regard that the fluid force and volume signals the valve to shut off. Again, the fluid properties would affect the calibration of this type of device. Additionally, a float would need to have a large range of vertical motion to meter a few quarts of chemical all the way up to forty or fifty gallons. Some consideration has been given to developing a float mounted on a track system.

Figure 19. An electronic float can record volume based on fluid levels.

The track would move the float to the necessary location as determined by the interface entry and identified by N2 Line Solutions during testing. Once the fluid reaches the float, the float would signal the product valve to close and the tank will contain the requested amount of product.

Once N_2 Line Solutions researched several options for measuring the chemical inputs, the team presented the information to Microfirm. Although the client found both flowmeters and volumetric sensing feasible, Mr. Dieball determined that flowmeters would be most practical for the batch chemical mixing system. Flowmeters can be found more regularly at spray equipment suppliers and could therefore be replaced more quickly when needed. Although some producers expressed the desire to physically see the amount of chemical entering the mixing system, Mr. Dieball is confident that a customized algorithm that continually supplies accurately mixed batches is all the visual a user will require.

Dr. Stone presented the team with several Raven flowmeters to use for testing, experimentation, and/or the final product. He also provided the team with the following information and rules of thumb.

Figure 20. Two inch, 220 flanged Raven flowmeter.

- Most flowmeters contain three wires in the plug: a ground, a power, and a signal wire.
- A flowmeter should have an arrow on the device indicating the direction of fluid flow.
- The flowmeter must have 10*I.D. of the flow meter length of straight pipe on the upstream and downstream side of the unit.
- Avoid turns and extra components in-line with the flowmeter to increase accuracy.

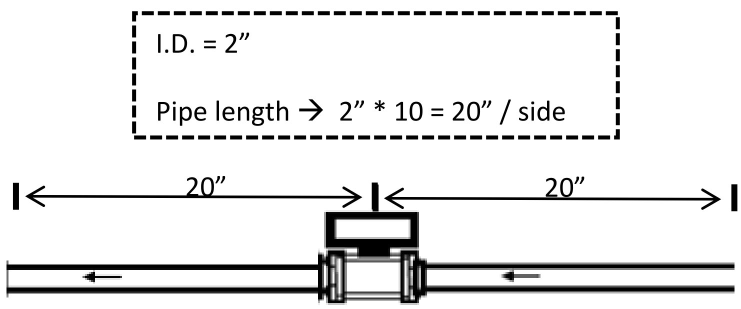
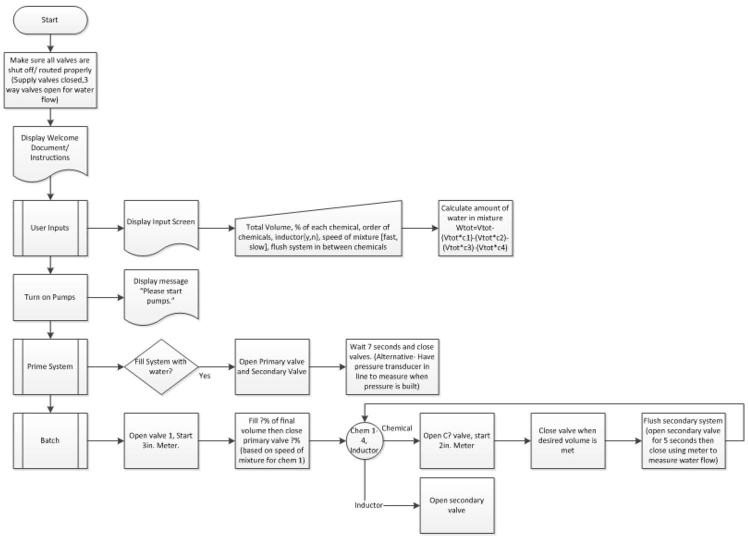


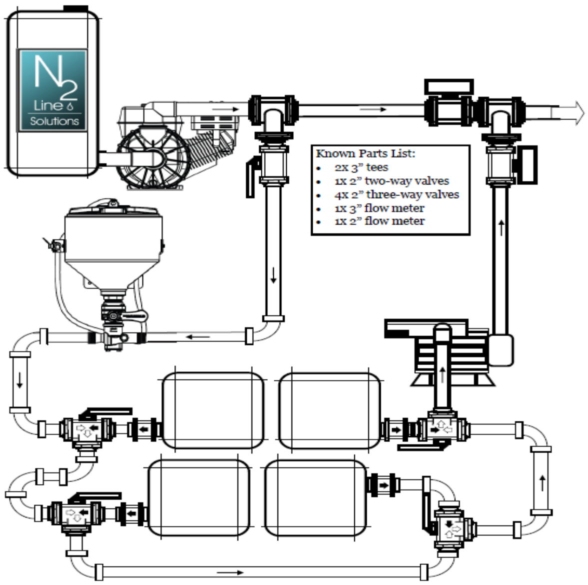
Figure 21. Two inch flowmeter plumbing requirements.

Experimentation and Simulation

N_2 Line Solutions will have extensive simulation to do with regard to testing the feasibility of metering devices. The team will consider the aforementioned flowmeters and volumetric monitoring devices and select one of the metering components to structure the prototype around. Additionally, the team must work to assembly a pump and power supply to deliver solution for the testing. Pump curves will need to be identified and flow rates will be noted with respect to the power supply. The team will also simulate several trials to determine the variances in volume of product delivered of varying chemical viscosities and densities.

Automating this system by writing code and controlling the controller and valves with the PLC will be the most tedious part of this project. The team will need to check the code's reliability and ensure it is functioning properly. Furthermore, the code should provide feedback to the operator. Once the flowrate or volume monitors have been selected and are available, numerous tests will be conducted to check the consistency and accuracy of the code as well as component efficacy.





Design Criterion

Constrants, etc.

Testing and Simulation

Lab, Field




The MixMaster Platform

Each component breakdown. Why we made decisions.

Sketches.

Component Specifications

December Proposal

Pictures, drawings, and details.

Cost Analysis

Budget, components, manufacturing, and comparison to competition if any.

ABC Mixing System							
#	Component	Size	Requirements	Other	Notes	Potential Vendors	Cost
1	Primary Centrifugal Pump with 13hp Honda	3" In/Out with 350gpm	300gpm	360 with no head	13hp Honda. 3" Wet Seal Centrifugal. 65 max psi. 3500 rpm.	Schaben	$ 1,700.00
1	Secondary Centrifugal Pump with 3.5hp Motor	2' In/Out with ~70gpm	75gpm			Schaben	$ 500.00
1	Eductor Cleanload	Hypro	35ga		2" outlet. Tank/Stand	Hypro/Banjo	$ 460.00
1	Flow Meter	Banjo-Raven			2" Banjo 300gpm. No Regulation. Closed Electric.	Schaben	$ 625.00
1	Flow Meter	Banjo			3" Banjo 14-670gpm. No Regulation. Closed Electric.	Schaben	$ 780.00
2	2" Schedule 80 PVC	Drisco			2" -- 20' joints	Federal Corp.	$ 68.40
1	3" Schedule 80 PVC	Drisco			3" -- 20' joints	Federal Corp.	$ 70.80
5	4 Electric Valve Manifold	Banjo			4bolt, 2". EV204FP. 12 Volt DC. 3.5amp Fuse. 1.25 sec cycle	2way ball	$ 1,775.00
1	Electric Valve	Banjo			6bolt, 3". EV300FP. 12 Volt DC. 3.5amp Fuse. 1.25 sec cycle	2way ball	$ 966.00
1	2" Hose		30'		suction	Schaben	$ 50.00
1	3" Hose		50'		supply and return	Schaben	$ 250.00
1	Fittings (3")	Banjo	Next Page			Schaben	$ 369.19
1	Fittings (2" sub system)	Banjo	Next Page			Schaben	$ 128.11
1	Fittings (Other)	Banjo	Next Page			Schaben	$ 100.76
6	Check valves and misc	Banjo				Schaben	$ 120.00
4	IBCs				Borrowed from Matt Steinert	Steinert	$ -
1	Devilbiss PLC HEC-HMI-C2151-E-R	Devilbiss			May use PLC provided	Stone	$ 568.00
1	Wiring and connectors						$ 150.00
1	Wiring protection						$ 100.00
1	Fiberglass protective box						$ 80.00
1	Platform Materials & Construction					Wayne Kiner	$ 250.00
							$ 9,111.26

Impact

Global

Industrial

User

Safety

Conclusions

Our product….

Team Information

Website, etc

Bibliography

Arduino. Retrieved October 21, 2011 from Arduino Electronics:

http://www.arduino.cc/

Dan D Rental. Retrieved October 19, 2011 from Web Services: http://sites.ararental.org/portals/dandrental/itemsforrent/Trailers.aspx

Divelbiss Corporation. Retrieved October 21, 2011 from Control Products:

http://www.divelbiss.com/Products/CatDetails.asp?ProdCatID=1

JD Skiles Company. Retrieved October 19, 2011 from JD Skiles: http://www.jdskiles.com/pitstopsprayertrailer.html

Penton Media, Inc. Retrieved October 20, 2011 from Farm Industry News:

http://farmindustrynews.com/sprayers/high-capacity-self-propelled-sprayers-0

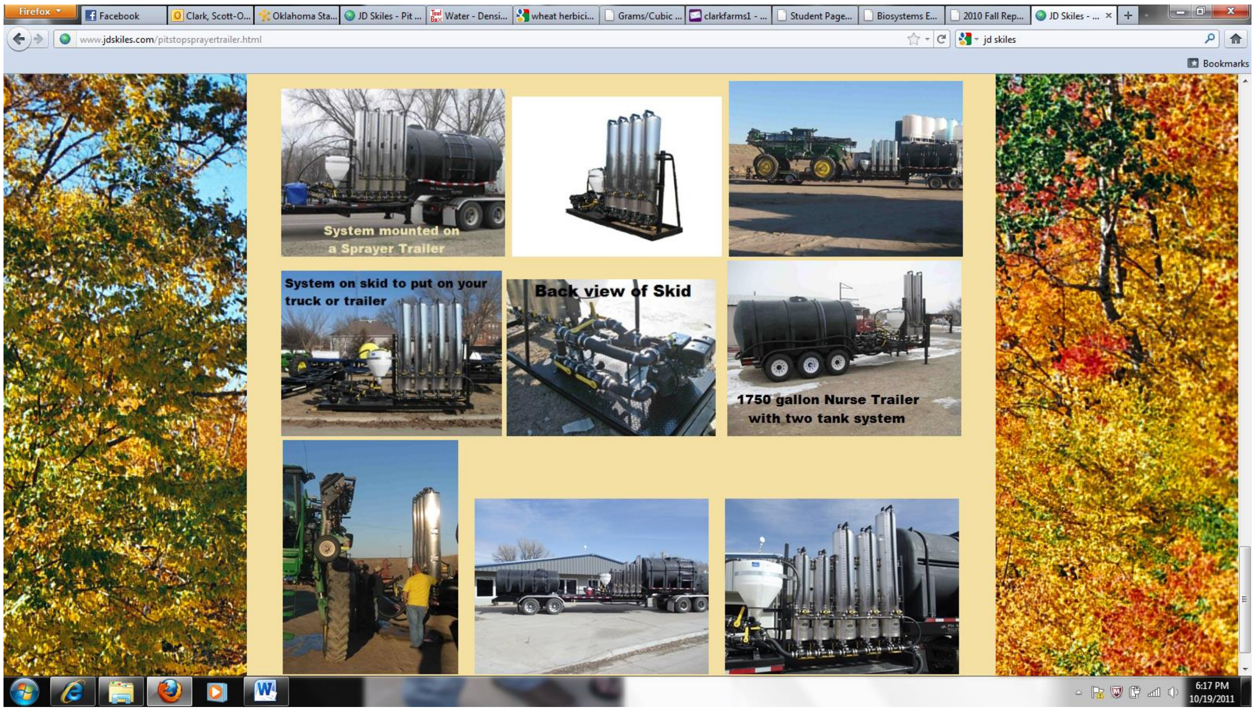
Portable Tank Group. Retrieved October 19, 2011 from Water Storage Tank:

http://www.water-storage-tank.com/poly-tank-for-drinking-water.html

Strain Measurement Devices. Retrieved October 21, 2011 from Float Switch and Liquid Level Sensor Products: http://www.fluidswitch.com/index.htm

Appendixes

Supporting Documents



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FEATURES
- 316 stainless steel construction.
- FKM (viton type), EPDM & Kalrez face seals.
- 100% PTFE ball seats.
- 100 P.S.I. maximum operating pressure.
- 300°F maximum operating temperature.
- Spillage Data: 1" = 1ml, 1½" and 2" = 2ml
- When liquid is flowing, Dry-Mate halves cannot be uncoupled without turning handles to closed position.
- When Dry-Mate halves are apart, handles cannot be turned to open position.

APPLICATIONS
- Agriculture
- Industrial
- Pharmaceutical
- Chemical processing

SIZES
- Sizes: 1" Full Port, 1½" Full Port and 2" Standard Port (Female NPT & BSP Threads)

PREVENTS ACCIDENTAL SPILLS AND EXPOSURE!

Male & Female shown coupled together.
Male & Female sold separately as shown below.

1" FULL PORT STAINLESS STEEL DRY-MATE						
PART NO	DESCRIPTION	MAX PSI	PIPE SIZE	OPENING THRU BALL	QTY	PRICE
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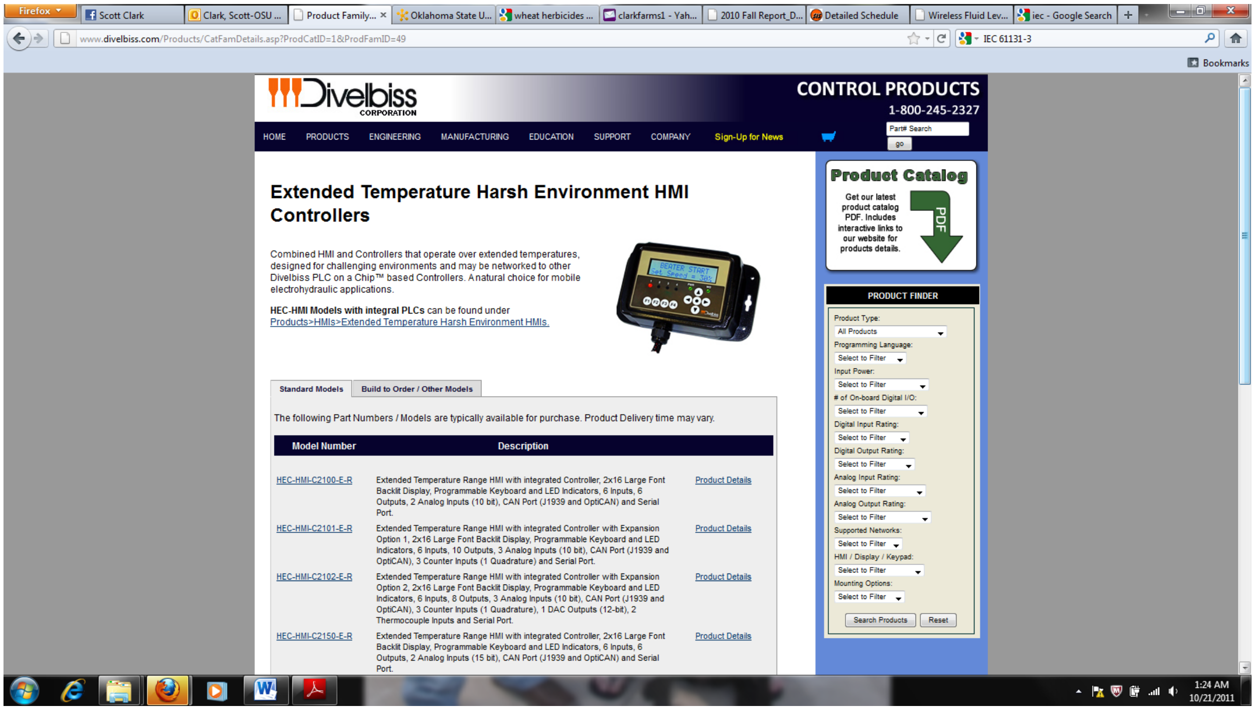
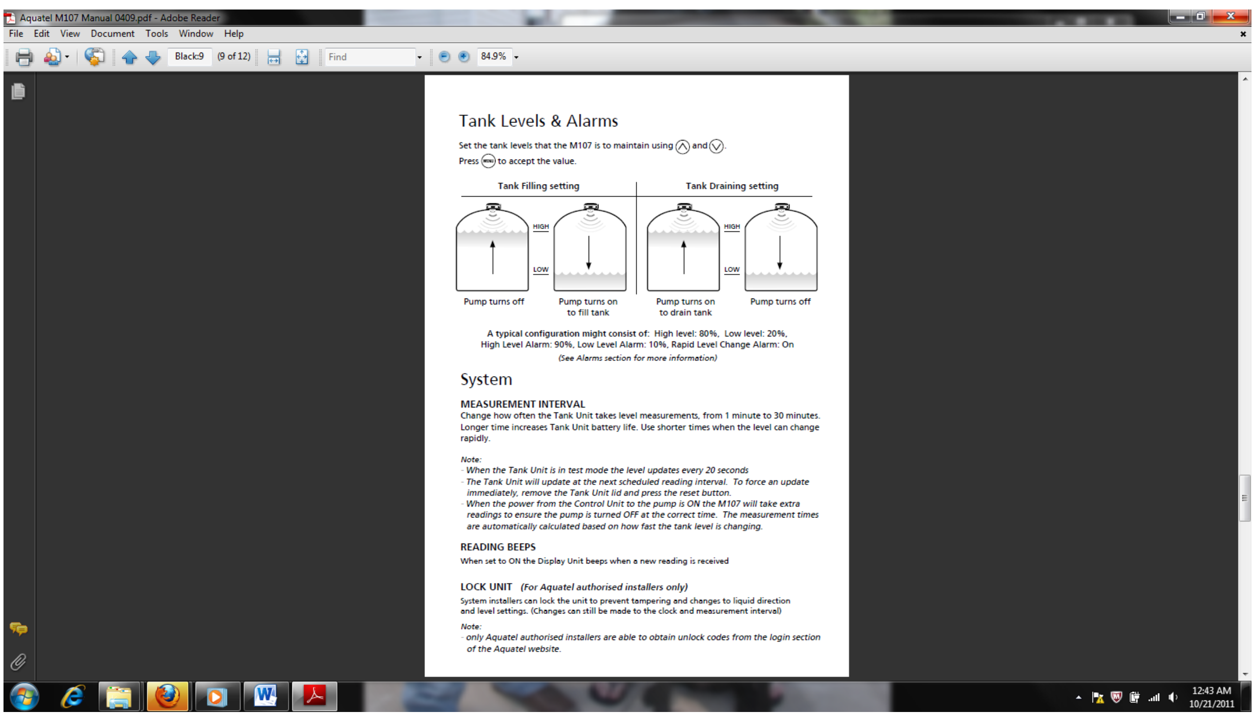
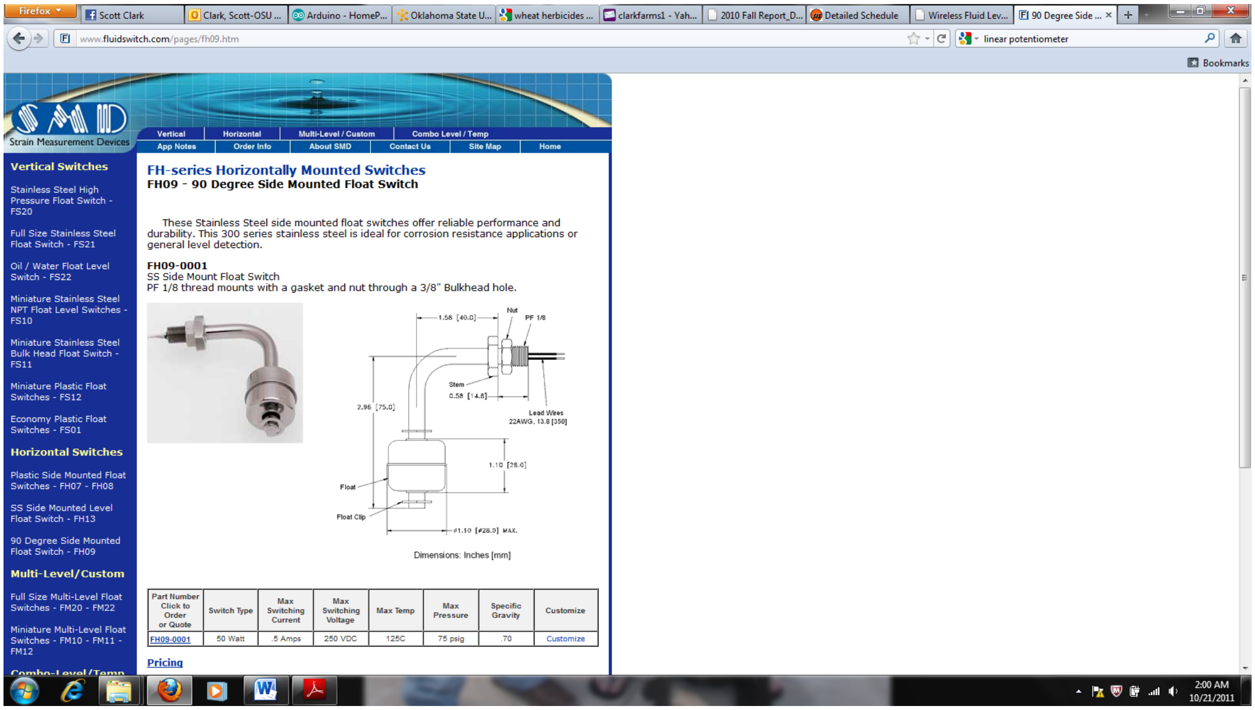
DM100ABSS	1" Male x BSP w/PTFE Seals	100	1"	1"	1	$488.09
DM100DSS	1" Female x NPT w/FKM(viton type) Seals	100	1"	1"	1	$589.51
DM100DSSE	1" Female x NPT w/EPDM Seals	100	1"	1"	1	$589.51
DM100DSST	1" Female x NPT w/Kalrez®Seals	100	1"	1"	1	$1,869.96
DM100DBSS	1" Female x BSP w/FKM(viton type) Seals	100	1"	1"	1	$589.51
DM100DBSSE	1" Female x BSP w/EPDM Seals	100	1"	1"	1	$589.51
DM100DBSST	1" Female x BSP w/Kalrez®Seals	100	1"	1"	1	$1,869.96

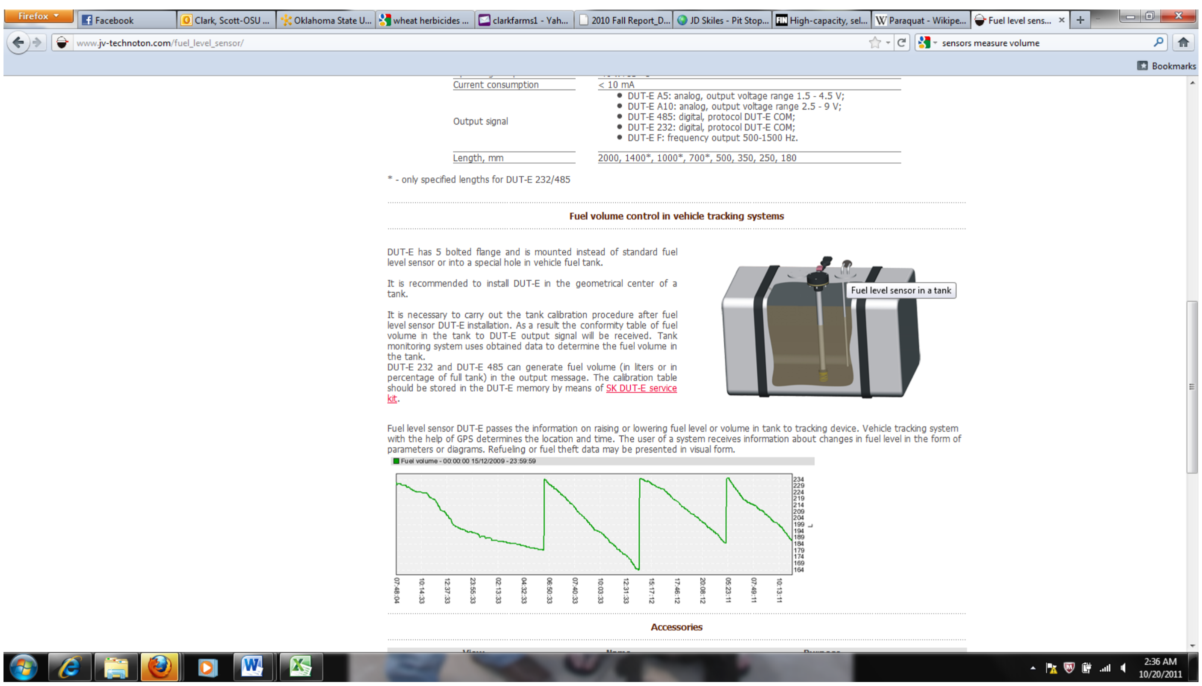
EASY CAM LEVER ACTION! THE MOST RECOGNIZED STYLE IN FLUID CONNECTION!

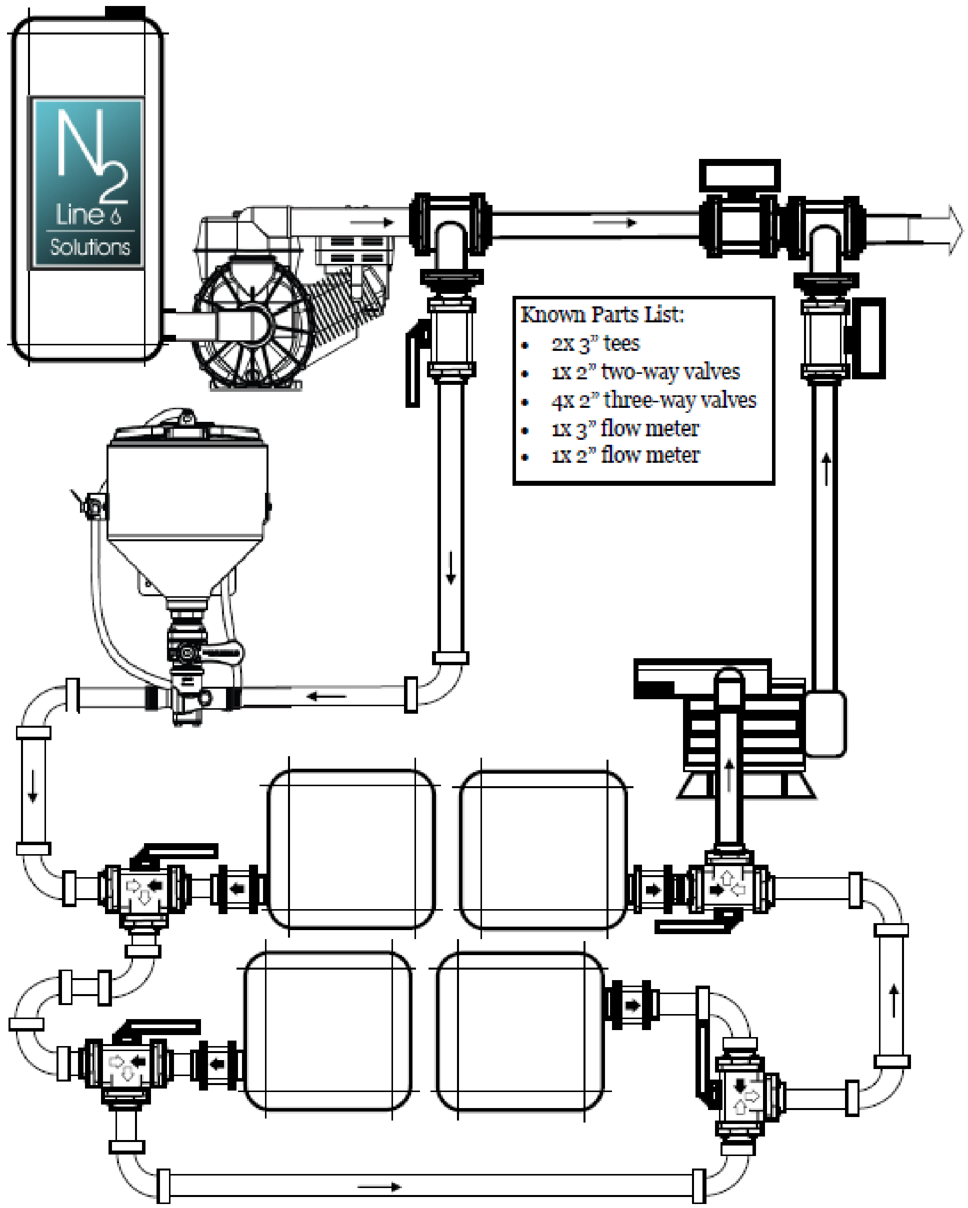
Male & Female sold separately as shown below.

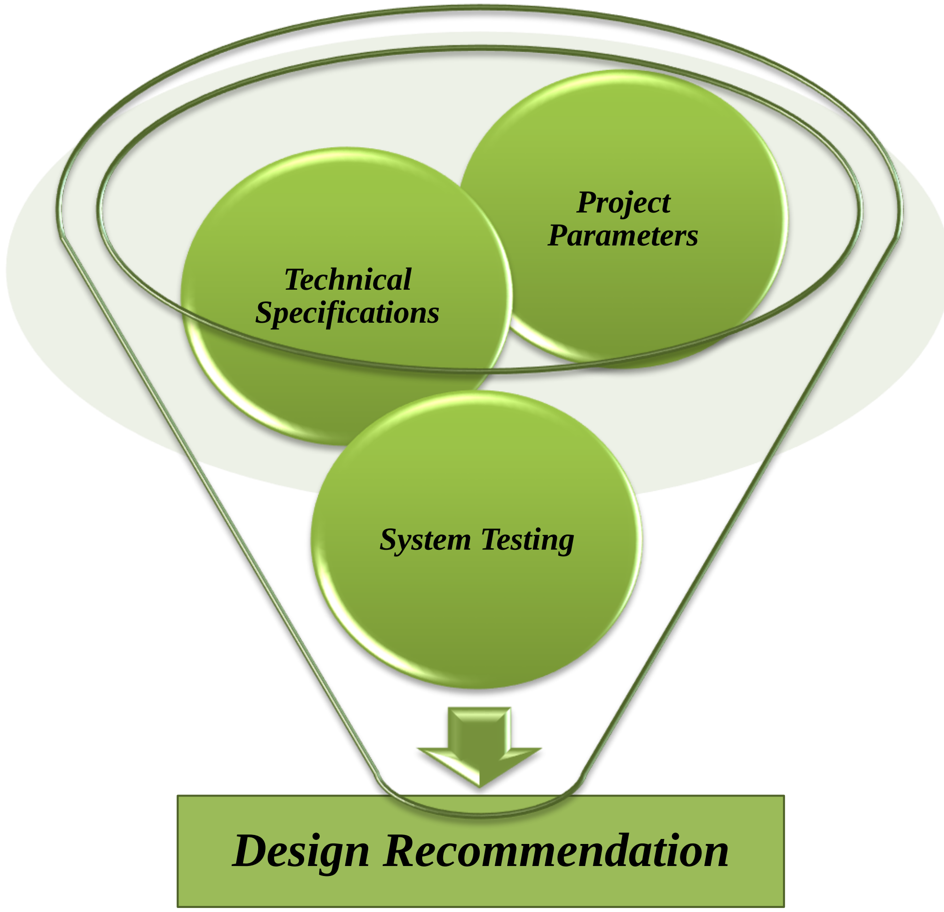

Divelbiss CORPORATION
CONTROL PRODUCTS
1-800-245-2327
HOME PRODUCTS ENGINEERING MANUFACTURING EDUCATION SUPPORT COMPANY Sign-Up for News
Extended Temperature Harsh Environment HMI Controllers
Combined HMI and Controllers that operate over extended temperatures, designed for challenging environments and may be networked to other Divelbiss PLC on a Chip™ based Controllers. A natural choice for mobile electrohydraulic applications.
HEC-HMI Models with integral PLCs can be found under Products>HMIs>Extended Temperature Harsh Environment HMIs.
Standard Models
Build to Order / Other Models
The following Part Numbers / Models are typically available for purchase. Product Delivery time may vary.
Model Number
Description
HEC-HMI-C2100-E-R
Extended Temperature Range HMI with integrated Controller, 2x16 Large Font Backlit Display, Programmable Keyboard and LED Indicators, 6 Inputs, 6 Outputs, 2 Analog Inputs (10 bit), CAN Port (J1939 and OptiCAN) and Serial Port.
Product Details
HEC-HMI-C2101-E-R
Extended Temperature Range HMI with integrated Controller with Expansion Option 1, 2x16 Large Font Backlit Display, Programmable Keyboard and LED Indicators, 6 Inputs, 10 Outputs, 3 Analog Inputs (10 bit), CAN Port (J1939 and OptiCAN), 3 Counter Inputs (1 Quadrature) and Serial Port.
Product Details
HEC-HMI-C2102-E-R
Extended Temperature Range HMI with integrated Controller with Expansion Option 2, 2x16 Large Font Backlit Display, Programmable Keyboard and LED Indicators, 6 Inputs, 8 Outputs, 3 Analog Inputs (10 bit), CAN Port (J1939 and OptiCAN), 3 Counter Inputs (1 Quadrature), 1 DAC Outputs (12-bit), 2 Thermocouple Inputs and Serial Port.
Product Details
HEC-HMI-C2150-E-R
Extended Temperature Range HMI with integrated Controller, 2x16 Large Font Backlit Display, Programmable Keyboard and LED Indicators, 6 Inputs, 6 Outputs, 2 Analog Inputs (15 bit), CAN Port (J1939 and OptiCAN) and Serial Port.
Product Details
Product Catalog
Get our latest product catalog PDF. Includes interactive links to our website for products details.
PDF
PRODUCT FINDER
Product Type:
Programming Language:
Input Power:
# of On-board Digital I/O:
Digital Input Rating:
Digital Output Rating:
Analog Input Rating:
Analog Output Rating:
Supported Networks:
HMI / Display / Keypad:
Mounting Options:
Search Products
Reset


Aquatel M107 Manual 0409.pdf - Adobe Reader
Tank Levels & Alarms
Set the tank levels that the M107 is to maintain using and .
Press to accept the value.
Tank Filling setting
Tank Draining setting
HIGH
LOW
Pump turns off
Pump turns on to fill tank
Pump turns on to drain tank
Pump turns off
A typical configuration might consist of: High level: 80%, Low level: 20%, High Level Alarm: 90%, Low Level Alarm: 10%, Rapid Level Change Alarm: On
(See Alarms section for more information)
System
MEASUREMENT INTERVAL
Change how often the Tank Unit takes level measurements, from 1 minute to 30 minutes. Longer time increases Tank Unit battery life. Use shorter times when the level can change rapidly.
Note:
· When the Tank Unit is in test mode the level updates every 20 seconds
· The Tank Unit will update at the next scheduled reading interval. To force an update immediately, remove the Tank Unit lid and press the reset button.
· When the power from the Control Unit to the pump is ON the M107 will take extra readings to ensure the pump is turned OFF at the correct time. The measurement times are automatically calculated based on how fast the tank level is changing.
READING BEEPS
When set to ON the Display Unit beeps when a new reading is received
LOCK UNIT (For Aquatel authorised installers only)
System installers can lock the unit to prevent tampering and changes to liquid direction and level settings. (Changes can still be made to the clock and measurement interval)
Note:
· only Aquatel authorised installers are able to obtain unlock codes from the login section of the Aquatel website.


www.fluidswitch.com/pages/fh09.htm
Strain Measurement Devices
Vertical Switches
Stainless Steel High Pressure Float Switch - FS20
Full Size Stainless Steel Float Switch - FS21
Oil / Water Float Level Switch - FS22
Miniature Stainless Steel NPT Float Level Switches - FS10
Miniature Stainless Steel Bulk Head Float Switch - FS11
Miniature Plastic Float Switches - FS12
Economy Plastic Float Switches - FS01
Horizontal Switches
Plastic Side Mounted Float Switches - FH07 - FH08
SS Side Mounted Level Float Switch - FH13
90 Degree Side Mounted Float Switch - FH09
Multi-Level/Custom
Full Size Multi-Level Float Switches - FM20 - FM22
Miniature Multi-Level Float Switches - FM10 - FM11 - FM12
FH-series Horizontally Mounted Switches
FH09 - 90 Degree Side Mounted Float Switch
These Stainless Steel side mounted float switches offer reliable performance and durability. This 300 series stainless steel is ideal for corrosion resistance applications or general level detection.
FH09-0001
SS Side Mount Float Switch
PF 1/8 thread mounts with a gasket and nut through a 3/8" Bulkhead hole.
Dimensions: Inches [mm]
Part Number Click to Order or Quote | Switch Type | Max Switching Current | Max Switching Voltage | Max Temp | Max Pressure | Specific Gravity | Customize
FH09-0001 | 50 Watt | .5 Amps | 250 VDC | 125C | 75 psig | .70 | Customize
Pricing


www.jv-technoton.com/fuel_level_sensor/
Current consumption < 10 mA
Output signal
DUT-E A5: analog, output voltage range 1.5 - 4.5 V;
DUT-E A10: analog, output voltage range 2.5 - 9 V;
DUT-E 485: digital, protocol DUT-E COM;
DUT-E 232: digital, protocol DUT-E COM;
DUT-E F: frequency output 500-1500 Hz.
Length, mm 2000, 1400*, 1000*, 700*, 500, 350, 250, 180
* - only specified lengths for DUT-E 232/485
Fuel volume control in vehicle tracking systems
DUT-E has 5 bolted flange and is mounted instead of standard fuel level sensor or into a special hole in vehicle fuel tank.
It is recommended to install DUT-E in the geometrical center of a tank.
It is necessary to carry out the tank calibration procedure after fuel level sensor DUT-E installation. As a result the conformity table of fuel volume in the tank to DUT-E output signal will be received. Tank monitoring system uses obtained data to determine the fuel volume in the tank.
DUT-E 232 and DUT-E 485 can generate fuel volume (in liters or in percentage of full tank) in the output message. The calibration table should be stored in the DUT-E memory by means of SK DUT-E service kit.
Fuel level sensor in a tank
Fuel level sensor DUT-E passes the information on raising or lowering fuel level or volume in tank to tracking device. Vehicle tracking system with the help of GPS determines the location and time. The user of a system receives information about changes in fuel level in the form of parameters or diagrams. Refueling or fuel theft data may be presented in visual form.
Accessories


N2 Line Solutions
Known Parts List:
• 2x 3" tees
• 1x 2" two-way valves
• 4x 2" three-way valves
• 1x 3" flow meter
• 1x 2" flow meter

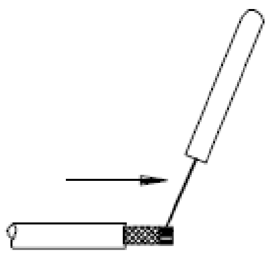

Project
Parameters
Technical
Specifications
System Testing
Design Recommendation

FLOW AND SPEED CABLE REPAIR

If cable has braid in it, start here. If cable does not contain braid, start with step 6.

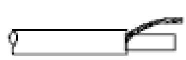
1) Remove approximately 1/2" of exterior insulation from end of shielded cable.

2) Comb braid by drawing a pick across the end of braided shield of cable. Gradually rotate and move into braid as stands are straightened out.

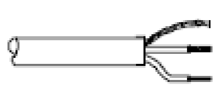


3) Part wire strands taking half to each side of cable and remove one side by cutting off strands as close as possible to exterior insulation.

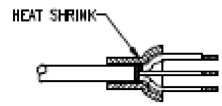
4) Twist remaining strands of wire between your thumb and index finger forming a tight wire.



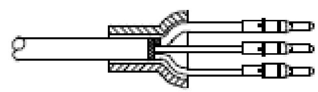
5) Remove paper liner around remaining wires and strip of approximately 1/4" of the insulation off each.



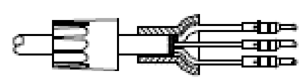
6) Install teflon tubing over the shield wire. Place heat shrink over cable as shown below. Shrink heat shrink down until snug around cable.



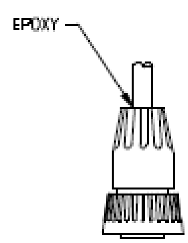
7) Solder or crimp appropriate (male, female) pins to wires.



8) Insert wire through back shell as shown, Insert appropriate wires to into plug connector. See flow ext. Cable or speed ext. Cable schematic for appropriate pin insertion for connector and cable type.



9) Fasten back shell to connector plug and fill back shell with 5 minute epoxy.



6

Will the **mini bulks** you plan to **use and refill** meet the new **EPA regulations** that are in affect August 17, 2011?

What does the new EPA regulation mean for your re-fillable mini bulks ***"any container you plan to refill with Ag pesticides must be compliant with the new regulation or be completely rinsed between each fill?***

Key container requirements of the new EPA regulations:

- All openings (except vents) must have one way valves, tamper evident devices or both
- The container must have a unique method of identification (serial number)
- The container must be compatible with the pesticide
- The container must meet DOT design, construction and marking for packaging group 3, or be listed as "an approved container for refill, in your bulk refill agreement from the registrant
- EPA Est. # and net contents must be on product label affxed to the tank
- Onsite record keeping must be kept for each inspection and fill

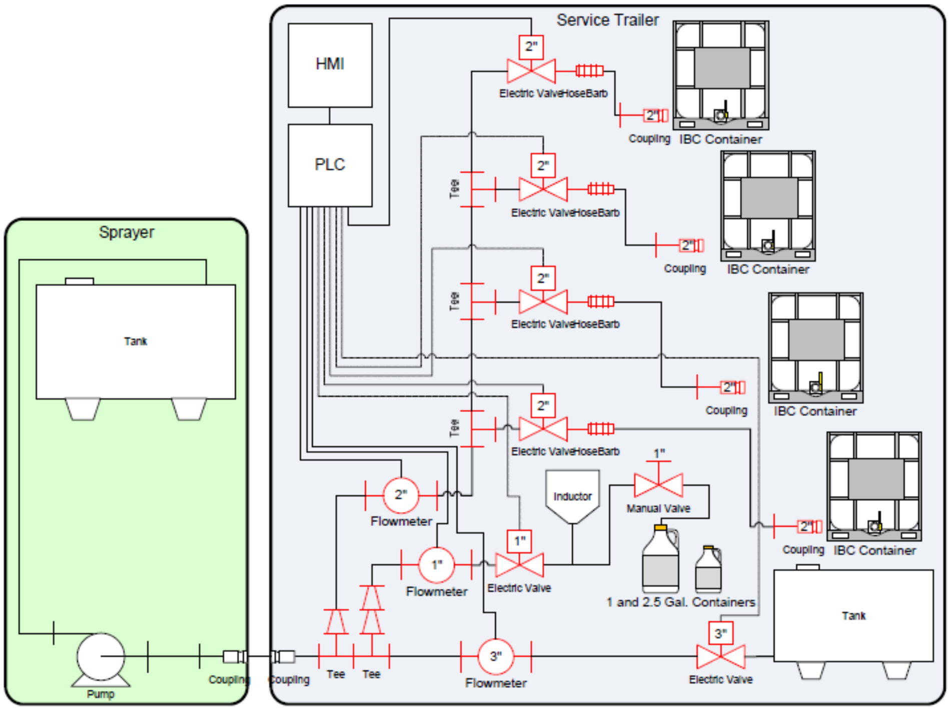
Your "check list" for compliance:

- **Bottom drain valve** – must have approved one-way valve and tamper evidence device to prevent valve removal or any backfilling
- **Top openings** – must have approved one-way valve or tamper evidence device on a solid bung or solid lid
- **Pumps** – **If integrally mounted, shipped and returned with the mini bulk** must have an approved one way valve to prevent backfilling of the container through the pump and a tamper evidence device from the pump to the container to indicate if the pump is removed from the container. Farm Chem has tested all pumps commonly used in the ag chemical market and found that **none of the commonly used pumps, for ag chemcials are compliant with the new EPA regulation.**

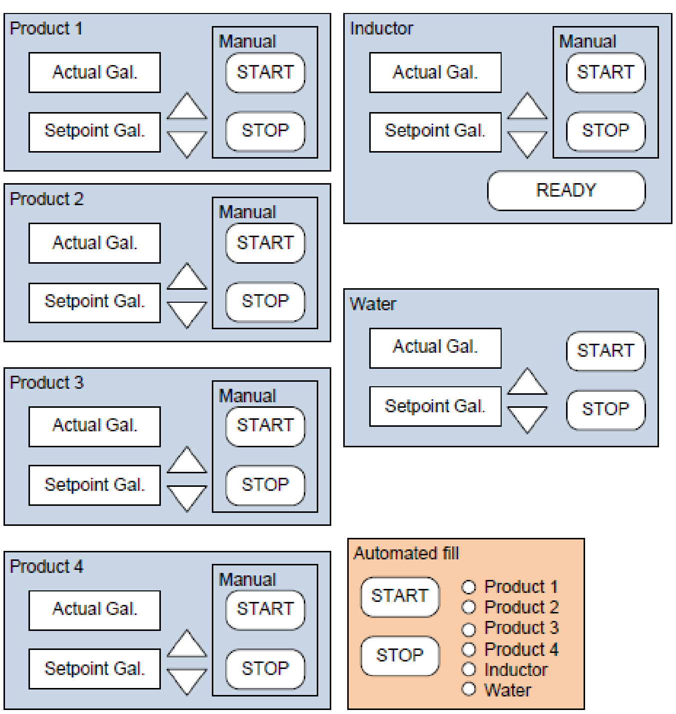



Farm Chem has met the challenge and can provide you with ALL of the one way valves, seals, and other devices to make the mini bulks you currently have in stock, that you plan to refill, compliant with the new EPA regulation for as little as $9.00 per tank to no more than approximately $35.00 per tank.

Call Farm Chem today to order the parts you need to make YOUR refillable mini bulks EPA compliant, 800-247-1854.



A general concept for the control of the system is shown in the following figure. Again this figure provides only an aid in understanding the concept and should not be understood as a design solution.



Process

- Set the setpoint values for all products
- Clear the actual values
- Press start (each product is added until inductor is reached and process waits for "Ready" on the inductor, when the inductor is running, process continues with inductor and then finally water)
- START and STOP on each product allows product to be engaged manually

General

Consider making each product + inductor plus water as individual screens that can be paged through Move the Ready button for the inductor to the automatic screen and flash the Inductor status while waiting for it to be ready. The start/ Stop buttons and up/down buttons could be implemented as the PLC's buttons. Some other method on the plc buttons used to page through screens.

Table 1 - A selection of commercial herbicides containing phenoxy herbicides

Commercial name	Phenoxy component	Other component(s)	Use
2,4-D Amine	amine salt of 2,4-D	—	Broadleaf weeds in cereal areas
2,4-DB Herbicide	sodium salt of 2,4-DB	—	Broadleaf weeds in lucerne and new pasture
Banvine	amine salt of 2,4-D	amine salt of dicamba	Broadleaf weeds in turf and waste areas
2,4-D Ethyl hexyl ester	ethyle hexyl ester of 2,4-D	—	Broadleaf weeds in pasture
MCPA	potassium salt of MCPA	—	Broadleaf weeds in pastures and cereals
MCPB	sodium salt of MCPB	—	Broadleaf weeds in pastures and some crops
Tordon 50-D	amine salt of 2,4-D	amine salt of picloram	Perennial broadleaf weeds

Reactions
2,4-D can react in esterification, acid base and amine salt forming reactions as follows:

Automated Batch Chemical Mixing System

Scott Clark
Collin Boettcher
Eric Lam
Meredith Shiflet

Client

- MicroFirm Inc.
  - Kent Dieball, Dr. Marvin Stone
  - Specialize in agricultural electronics, automation, sensing technologies
    - Greenseeker
    - AIM Command

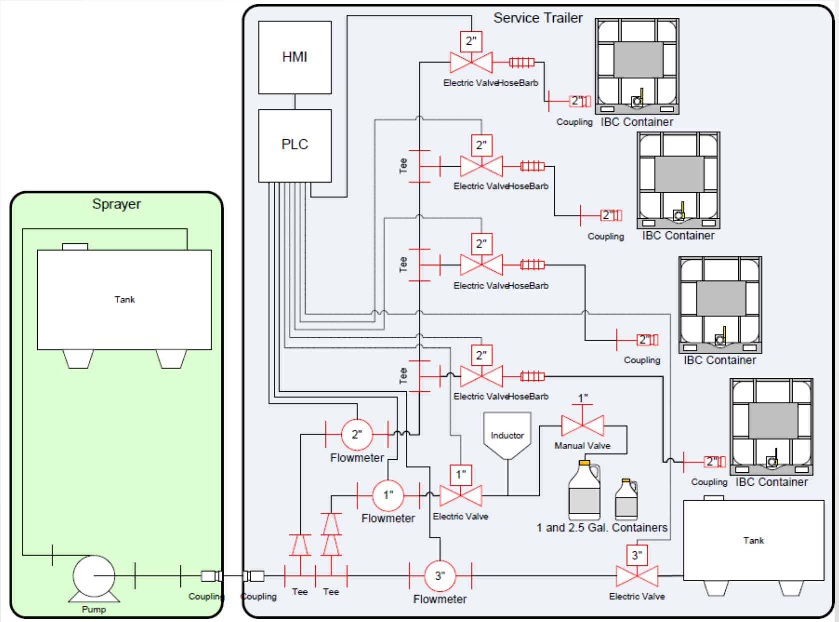
μFirm
Embedded System Development
CAN/J1939 Systems
Microfirm Inc.
Stillwater, Oklahoma 74074

Background

- Current chemical application
  - Manually measure chemicals
  - Switch small pump among chemical totes
  - Requires time, labor
  - Risk of spills, hazardous exposure

Design Objective

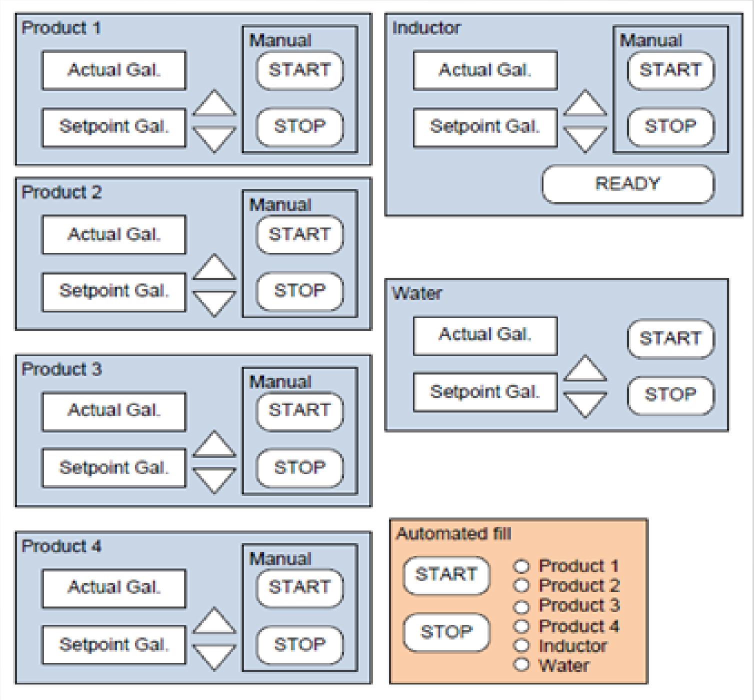
Develop an automated, batch chemical mixing system to be used in combination with a nurse trailer or filling rig for the agricultural industry.



Concept provided by Microfirm Inc.

Deliverables

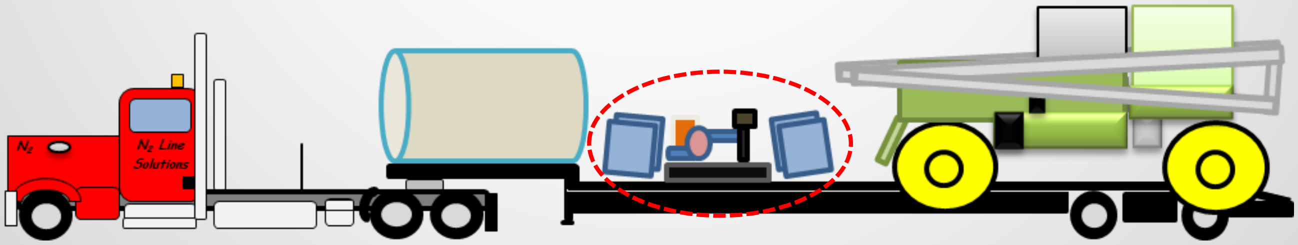
- Working Platform
  - Fully mobile
  - Automation algorithm & interface
  - Process 1200 gal carrier solution in 5 minutes
  - 4 Chemical inputs, inductor
  - Line clean-out
  - “Off the shelf” components



Concept provided by Microfirm Inc.

Customer

- Large scale chemical applicators
  - Sprayer with 90-120 ft booms
  - Acreage
    - Farmer >10000 acres/season
    - Commercial >20000 acres/season



Technical Research

- Investigate Market Saturation and Competition
  - Manual system's low cost is the primary competition

- No current system integrates multiple chemicals, in line, automatically with a simple interface.

Manual Mixing System Skid			
COMPONENT	UNITS	PRICE/UNIT	TOTAL COST
35ga Inductor	1	$400.00	$400.00
Primary Pump	1	$600.00	$600.00
Primary Gas Engine	1	$1,200.00	$1,200.00
Transfer Pump	1	$800.00	$800.00
Secondary Gas Engine	1	$800.00	$800.00
2" Valves	2	$50.00	$100.00
3" Valve	1	$120.00	$120.00
Hose	100	$2.50	$250.00
PVC Fittings	1	$300.00	$300.00
Platform Skid	1	$150.00	$150.00
2" Schedule 80 Pipe	20	$1.75	$35.00
3" Schedule 80 Pipe	20	$3.50	$70.00
Assembly Labor	15	$12.00	$180.00
Total Mixing System Cost			$5,005.00

Design Considerations

- Platform Pump vs Sprayer Suction Pump
  - Sprayer pump will not meet time requirements
  - Pump cavitation and suction head

- Flowmeters vs Volumetric Measurements
  - Visual verification
  - Flowmeter lifespan
  - Metering time

Power Source Considerations

- Hydraulic System Analysis
  - After starting generator, entire system can be operated from the interface
  - Determined to be out of scope and too expensive

Cost Projection for Hydraulic System

Component	Size	Est. Cost
Primary Centrifugal Pump	3" In/Out with 350 gpm	**$ 800**
Secondary Centrifugal Pump	2" In/Out with 75 gpm	**$ 600**
Primary Hydraulic Motor	8 gpm, 3600 rpm	**$ 500**
Secondary Hydraulic Motor	8 gpm, 3600 rpm	**$ 750**
Hydraulic Pump	2000 psi, 20 gpm	**$ 1,300**
Swoop Valves	8 gpm each	**$ 1,100**
Electrical Power Source	23 hp	**$ 2,000**
Gas Generator	17,135 Watts	**$ 3,000**
Hydraulic Hoses/Fittings		**$ 150.00**
Total Hydraulic Components Needed to Purchase:		**$ 10,200**

Competition

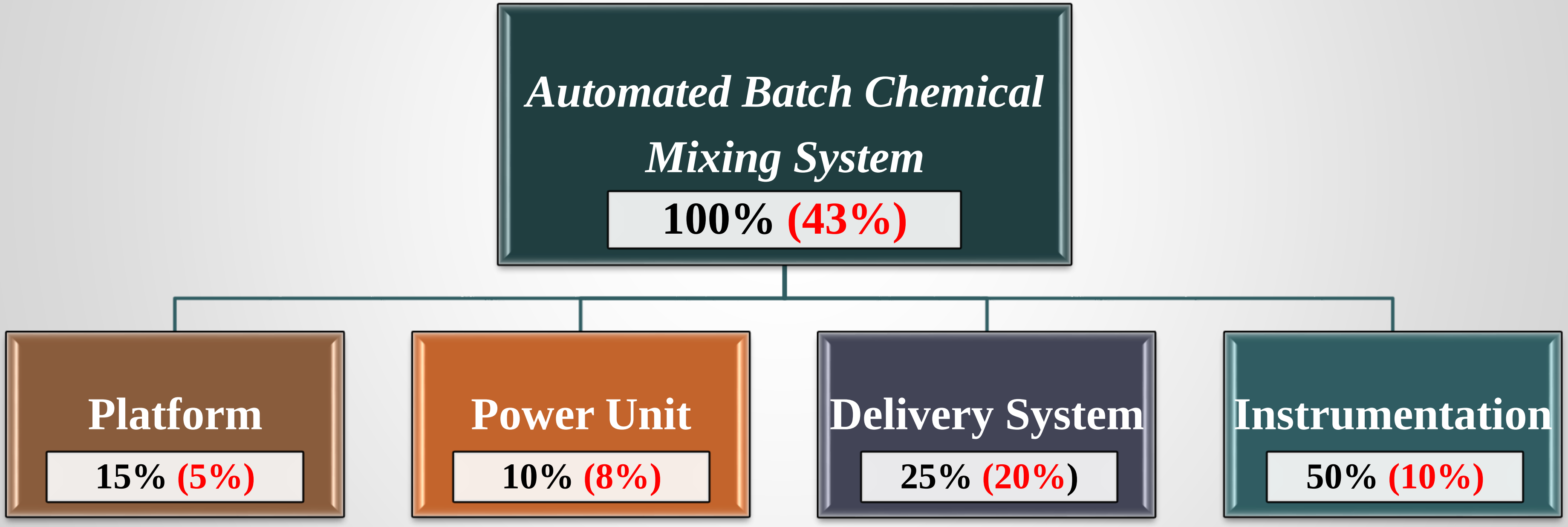
- JD Skiles Pitstop, Atwood, KS
  - Elite volumetric mechanical system
  - Mobile use

- The Kahler system
  - Automated chemical flow regulation
  - Ideal for indoor use

Competition

- John Deere & Co. – LoadCommand
  - Spray rig connects to tank for filling, automatically unhooks
  - System only allows for carrier solution transfer
- Raven Sidekick Pro Direct Injection
  - Provides a real-time injection of chemical onboard the applicator
  - Low injection rates with manual flow rate selection

Work Breakdown



Platform	Power Unit	Delivery System	Instrumentation
15% (5%)	10% (8%)	25% (20%)	50% (10%)

Platform
- CAD Design
- Frame
- Manufacture
- Mounts
- User Accessibility
- System Securement

Power Unit
- Pump Selection
- Power Requirement
- Automation
- Power Source

Delivery System
- Flow Metering
- Fluid Control
- Manual System
- Inductor Selection
- Manifold/Housing
- Chemical Injection
- Pressure Regulation
- Friction Loss
- System Cleanout

Instrumentation
- Controller Selection
- Interface Development
- Programming Software
- Algorithm Initiation
- Sub Programs
- Automation Testing
- Volume Determination
- Program Debugging
- System Testing
- Code Debugging
- Fluid Properties
- Robust Wiring / Hookup
- System Validation

Fall Activities

N2LS-1.0: Inventory components.

N2LS-2.0: Find test pumps and power sources.

N2LS-3.0: Assembly manual system.

N2LS-4.0: Test pumps and concepts.

N2LS-5.0: Test and assemble electrical components.

N2LS-6.0: Locate software, attain license and install.

N2LS-7.0: Meet with client regarding PLC.*

N2LS-8.0: Critique design and present.

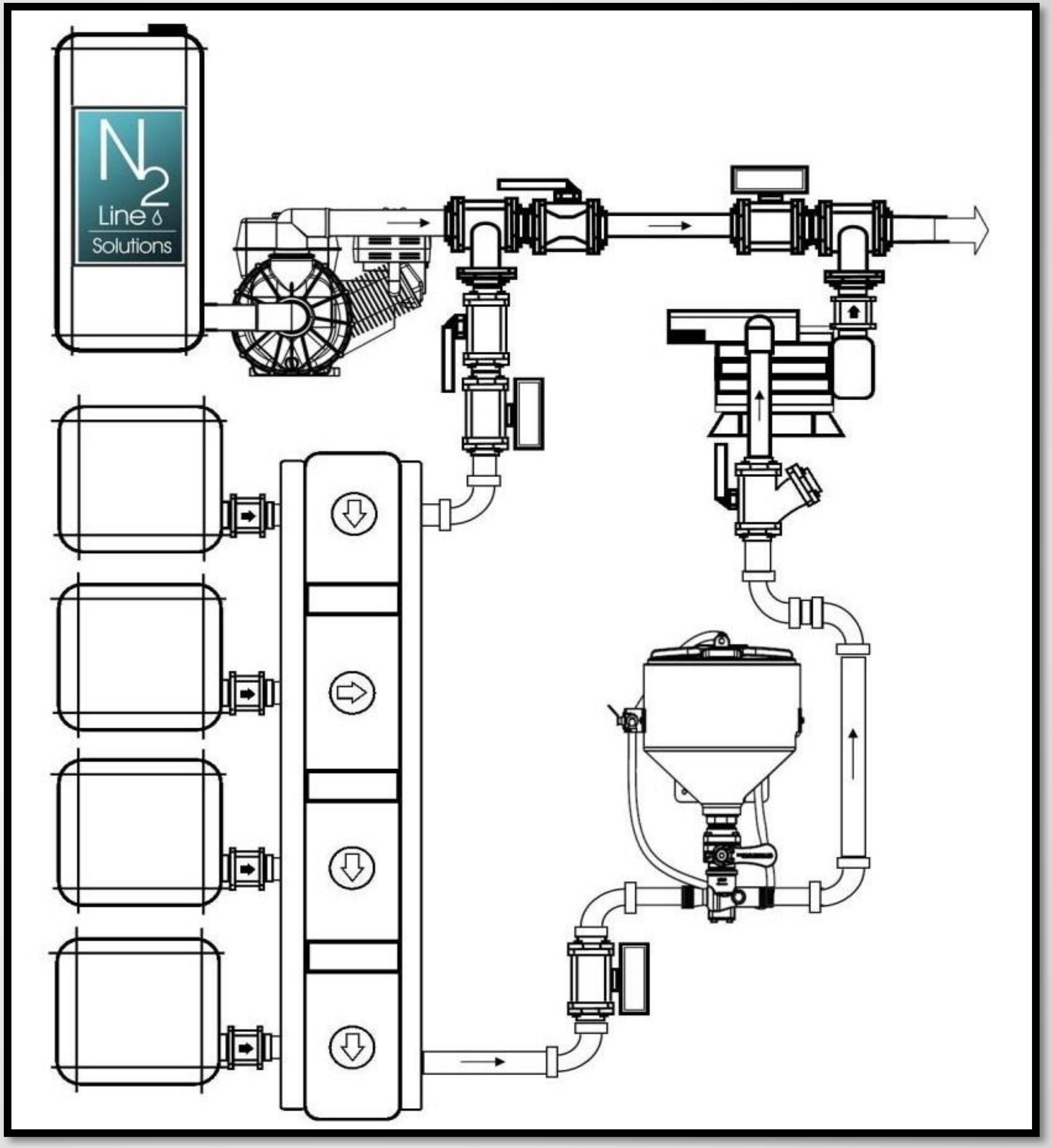
N2LS-9.0: Pickup IBCs and consult with Steinerts.

N2LS-10.0: Adjust design and develop mock system.

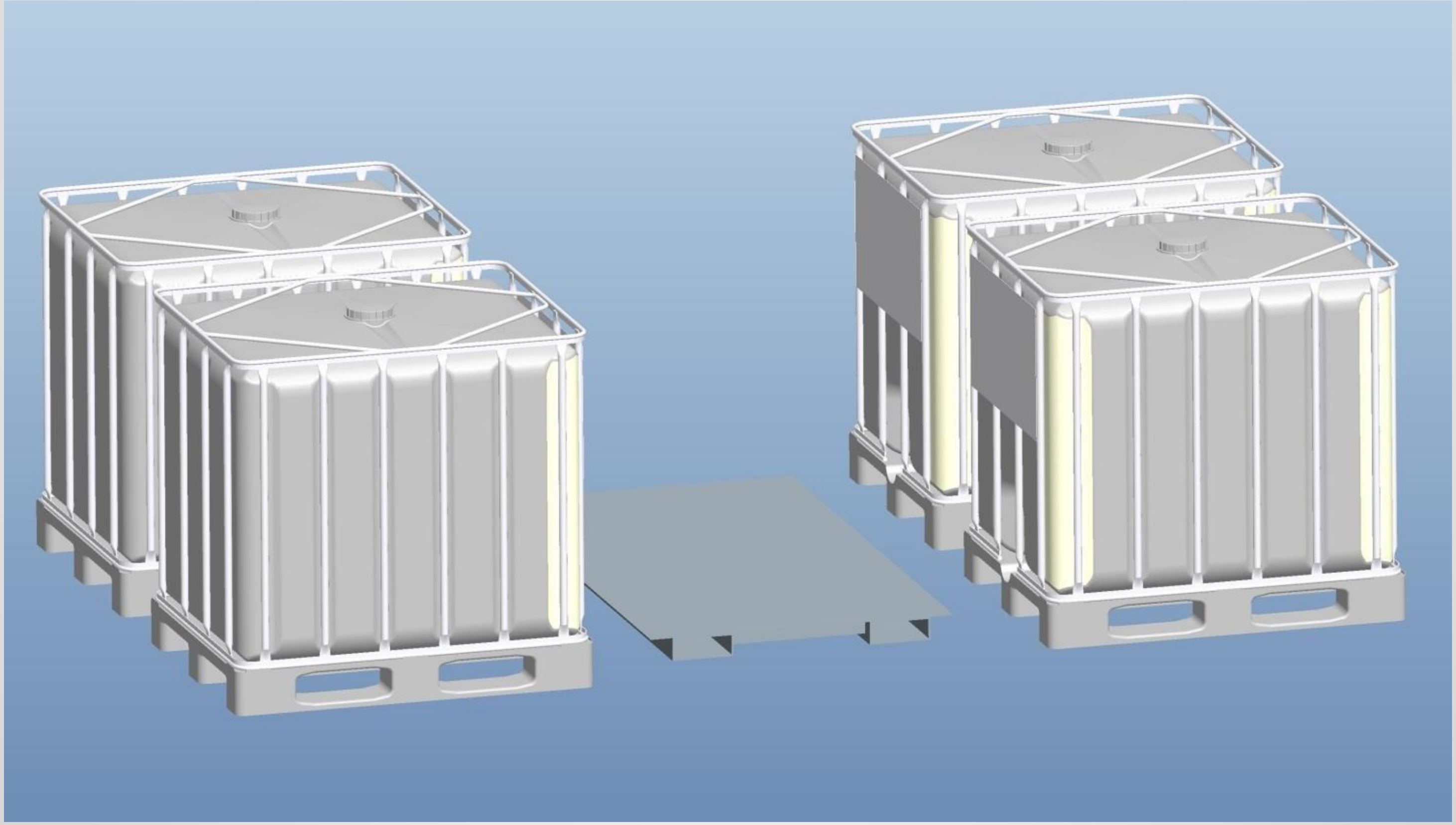
N2LS-11.0: Test system and run manually.

***** Software licensing delayed consultation***

Design

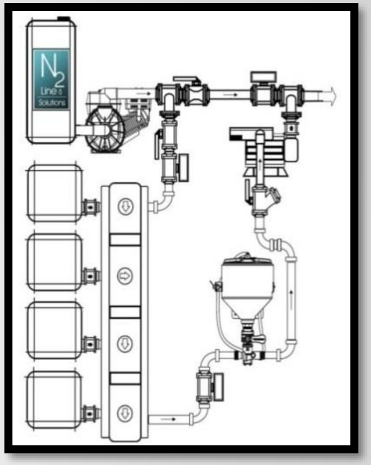


Platform



System Components- Plumbing/Valves

- Drisco Pipe
  - Carrier Solution Main Line & Housing - 3”
  - Secondary System / Chemical Loop - 2”
- Fittings
  - Banjo elbows, tees, couplings
- Valves
  - Banjo
    - 6 – 2” Automatic ball valves
    - 1 – 3” Automatic regulating valve



Banjo

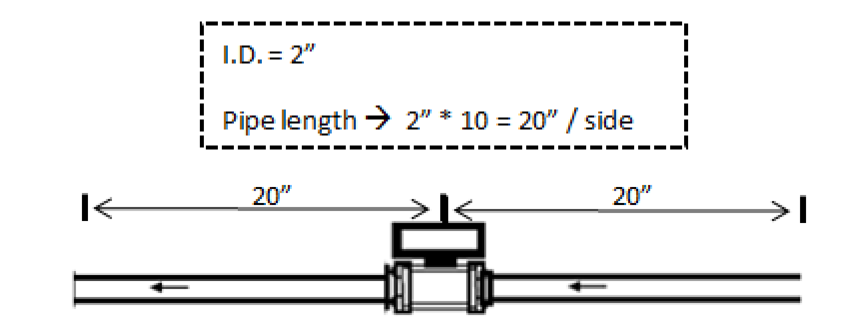
Components- Power/Pumps

- **Testing Pumps**
  - Main Source: 3 phase variable flow 10hp electric with 180gpm centrifugal pump
  - Secondary Source: 100 gpm with 5.5 Briggs & Stratton gas engine

- **Design**
  - Main Source: 13hp Honda gas engine with 360gpm Banjo centrifugal pump
  - Secondary Source: 80-100 gpm centrifugal pump with 5.5 Briggs & Stratton gas engine

Components- Metering

- Metering Devices controlled by PLC
  - 2 - Raven 2” 220 flow meter
  - 1 - Raven 3” 220 flow meter
  - Test metering accuracy with plumbing concepts
  - Push fluid through, not pull



Components- Electronics

- PLC Selection—12 I/O Count
  - Divelbiss
  - Allen Bradley
- Software
  - RS Logic
    - Ladder Diagram

User Prompt

1. Input Screen
   a) Chemical Information
      i. Totes 1 thru 4
      ii. Total Volume
      iii. Volume Each Chemical
      iv. Inductor (yes, no)

Interface

4 Stage Operation:

1. User Prompt
2. System Prime
3. Chemical Load Out
4. Clear-out

System Prime

2. Fill Lines
   a) Prime Secondary Pump
   b) Flowmeter Check

Interface

4 Stage Operation:

1. User Prompt
2. System Prime
3. Chemical Load Out
4. Clear-out

Chemical Load Out

3. Process Screen
   a) Tote Status
   b) Elapsed Time
   c) Override

Interface

4 Stage Operation:

1. User Prompt
2. System Prime
3. Chemical Load Out
4. Clear-out

Clear-out

4. Inductor
   a) Elapsed Time
   b) Completion Time
   c) Cleans Line

Interface

4 Stage Operation:

1. User Prompt
2. System Prime
3. Chemical Load Out
4. Clear-out

User Prompt

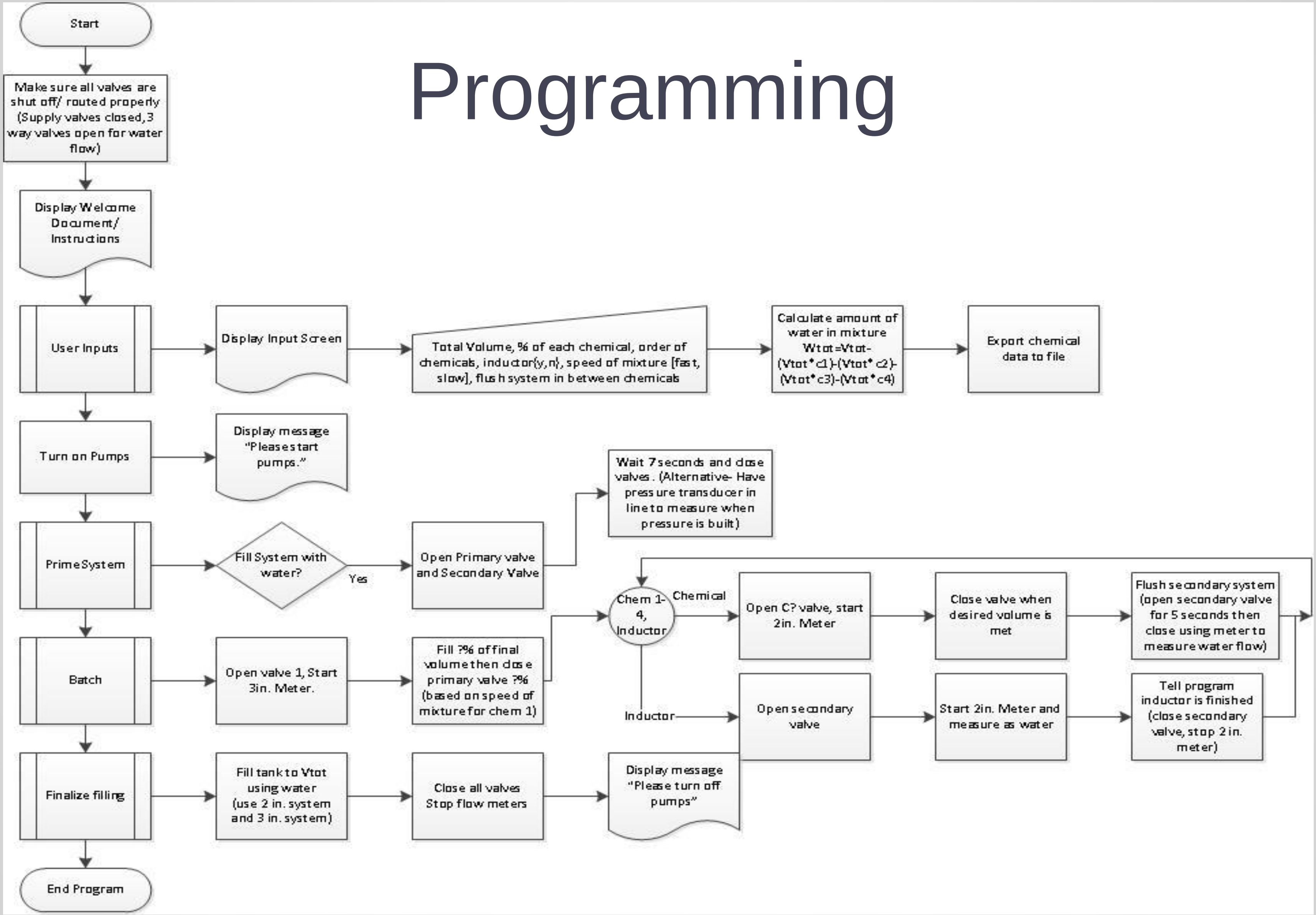
5. Log Screen
   a) Date
   b) Time
   c) Elapsed Time
   d) Chemical List
   e) Restart

Interface

4 Stage Operation:

1. User Prompt
2. System Prime
3. Chemical Load Out
4. Clear-out

Programming



Programming

I/O Controls	HMI

I/O Controls

- Ladder Diagram
- Develop Individual Subroutines

- Jan: Interface all I/O
- Feb: Integrate Timing
- March: Combine
- April: Debug

HMI

- Allen Bradley
- Sample Code Website

- Jan: Select HMI
- Feb: Load Graphics
- March: Combine
- April: Debug

Prototype Development

- Test valve operation
- Check flow meter accuracy
- Layout manual system
- Determine pump capabilities

Financial Analysis

System Cost Comparison								
Manual Mixing System Skid					Automated Mixing System Skid			
COMPONENT	UNITS	PRICE/UNIT	TOTAL COST		COMPONENT	UNITS	PRICE/UNIT	TOTAL COST
35ga Inductor	1	$400.00	$400.00		35ga Inductor	1	$400.00	$400.00
Primary Pump	1	$600.00	$600.00		Primary Pump	1	$600.00	$600.00
Primary Gas Engine	1	$1,200.00	$1,200.00		Primary Gas Engine	1	$1,200.00	$1,200.00
Transfer Pump	1	$800.00	$800.00		Secondary Pump	1	$400.00	$400.00
Secondary Gas Engine	1	$800.00	$800.00		Secondary Gas Engine	1	$800.00	$800.00
2" Valves	2	$50.00	$100.00		2" Electric Valve (manifold)	6	$200.00	$1,200.00
3" Valve	1	$120.00	$120.00		2" Flow Meters	1	$400.00	$400.00
Hose	100	$2.50	$250.00		3" Flow Meter	1	$700.00	$700.00
PVC Fittings	1	$300.00	$300.00		3" Electric Valve	1	$300.00	$300.00
Platform Skid	1	$150.00	$150.00		Wiring Harnesses	10	$20.00	$200.00
2" Schedule 80 Pipe	20	$1.75	$35.00		Electrical Box / Protection	1	$100.00	$100.00
3" Schedule 80 Pipe	20	$3.50	$70.00		Hose	100	$2.50	$250.00
					Battery	1	$50.00	$50.00
Assembly Labor	15	$12.00	$180.00		Controller (PLC)	1	$500.00	$500.00
					Human Interface	1	$400.00	$400.00
					PVC Fittings	1	$300.00	$300.00
					Platform Skid	1	$150.00	$150.00
					2" Schedule 80 Pipe	20	$1.75	$35.00
					3" Schedule 80 Pipe	20	$3.50	$70.00
					Assembly Labor	25	$12.00	$300.00
Total Mixing System Cost			$5,005.00		Total Mixing System Cost			$8,355.00

~ $3,350 cost increase ~

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Annual Savings and Generated Revenue Projection				
Standard Chemical Shuttle System			Automated Batch Chemical Mixing System	
Number of acres sprayed annually:	20000		Number of acres sprayed annually:	20000
Number of acres sprayed per hour:	100		Number of acres sprayed per hour:	100
Size of sprayer tank (ga)	1000		Size of sprayer tank (ga)	1000
Number of tanks filled per year:	2000		Number of tanks filled per year:	2000
Average time per tank fill (min)	15		Average time per tank fill (min)	5
Hours spent filling sprayer	500		Hours spent filling sprayer	167
Number of annual labor hours required: (spray + fill)	700		Number of annual labor hours required: (spray + fill)	367
Potential number of acres gained annually:	0		Potential number of acres gained annually:	33333
Revenue generated per acre:	$5.00		Revenue generated per acre:	$5.00
Potential annual revenue increase:	$0.00		Potential annual revenue increase:	$166,667
Annual cost of labor required to mix batches: ($12/hr)	$8,400		Annual cost of labor required to mix batches:	0
Annual cost of operator: ($18/hr)	$12,600		Annual cost of operator: ($18/hr)	$6,600
Annual cost of machine operation: ($80/hr)	$56,000		Annual cost of machine operation: ($80/hr)	$29,333
			Machine costs savings:	$26,667
			Annual machine fuel savings: (10gph) ($3/ga)	$10,000
Annual Cost of Manual System:	$77,000		Annual Cost of Automated System	$35,933
Automated System Annual Cost Savings and Revenue Generation			(Assumes Applicator Completes All Potential Acres)	$217,733
Automated System Annual Cost Savings and Revenue Generation			(Assumes Applicator Completes None of Potential Acres)	$51,067

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Annual Savings and Generated Revenue Projection				
Standard Chemical Shuttle System			Automated Batch Chemical Mixing System	
Number of acres sprayed annually:	10000		Number of acres sprayed annually:	10000
Number of acres sprayed per hour:	100		Number of acres sprayed per hour:	100
Size of sprayer tank (ga)	1000		Size of sprayer tank (ga)	1000
Number of tanks filled per year:	1000		Number of tanks filled per year:	1000
Average time per tank fill (min)	15		Average time per tank fill (min)	5
Hours spent filling sprayer	250		Hours spent filling sprayer	83
Number of annual labor hours required: (spray + fill)	350		Number of annual labor hours required: (spray + fill)	183
Potential number of acres gained annually:	0		Potential number of acres gained annually:	16667
Revenue generated per acre:	$5.00		Revenue generated per acre:	$5.00
Potential annual revenue increase:	$0.00		Potential annual revenue increase:	$83,333
Annual cost of labor required to mix batches: ($12/hr)	$4,200		Annual cost of labor required to mix batches:	0
Annual cost of operator: ($18/hr)	$6,300		Annual cost of operator: ($18/hr)	$3,300
Annual cost of machine operation: ($80/hr)	$28,000		Annual cost of machine operation: ($80/hr)	$14,667
			Machine costs savings:	$13,333
			Annual machine fuel savings: (10gph) ($3/ga)	$5,000
Annual Cost of Manual System:	$38,500		Annual Cost of Automated System	$17,967
Automated System Annual Cost Savings and Revenue Generation			(Assumes Applicator Completes All Potential Acres)	$108,867
Automated System Annual Cost Savings and Revenue Generation			(Assumes Applicator Completes None of Potential Acres)	$25,533

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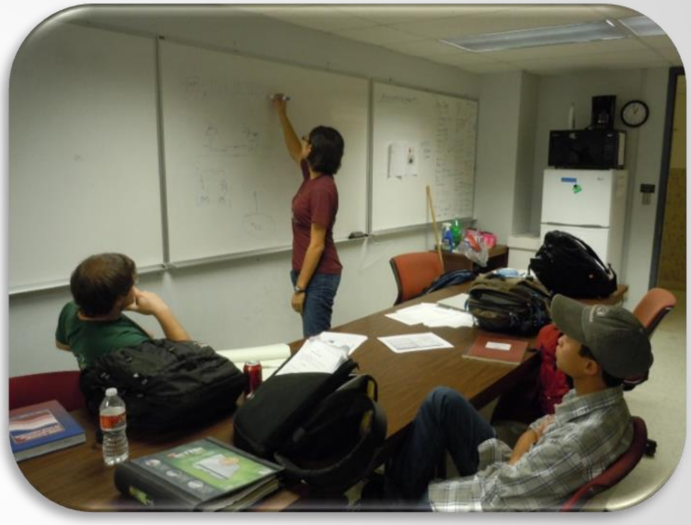
Annual Savings and Generated Revenue Projection				
Standard Chemical Shuttle System			Automated Batch Chemical Mixing System	
Number of acres sprayed annually:	20000		Number of acres sprayed annually:	20000
Number of acres sprayed per hour:	100		Number of acres sprayed per hour:	100
Size of sprayer tank (ga)	1000		Size of sprayer tank (ga)	1000
Number of tanks filled per day:	2000		Number of tanks filled per day:	2000
Average time per tank fill (min)	12		Average time per tank fill (min)	7
Hours spent filling sprayer	400		Hours spent filling sprayer	233
Number of annual labor hours required: (spray + fill)	600		Number of annual labor hours required: (spray + fill)	433
Potential number of acres gained annually:	0		Potential number of acres gained annually:	16667
Revenue generated per acre:	$5.00		Revenue generated per acre:	$5.00
Potential annual revenue increase:	$0.00		Potential annual revenue increase:	$83,333
Annual cost of labor required to mix batches: ($12/hr)	$7,200		Annual cost of labor required to mix batches:	0
Annual cost of operator: ($18/hr)	$10,800		Annual cost of operator: ($18/hr)	$7,800
Annual cost of machine operation: ($80/hr)	$48,000		Annual cost of machine operation: ($80/hr)	$34,667
			Machine costs savings:	$13,333
			Annual machine fuel savings: (10gph) ($3/ga)	$5,000
Annual Cost of Manual System:	$66,000		Annual Cost of Automated System	$42,467
Automated System Annual Cost Savings and Revenue Generation			(Assumes Applicator Completes All Potential Acres)	$111,867
Automated System Annual Cost Savings and Revenue Generation			(Assumes Applicator Completes None of Potential Acres)	$28,533

Spring Semester—What's Next?

- **Design Acceptance**
- **Component Purchasing**
- **Further Testing**
- **Program Development**
- **Troubleshooting**
- **Manufacturing Skid**
- **Assembly**
- **Final Testing and Validation**



Design Acceptance

- **Product work for Microfirm?**

Component Purchasing

Microfirm's Incurred Costs			
COMPONENT	UNITS	PRICE/UNIT	TOTAL EST. COST
15ga Handler Inductor with Venturi	1	$800.00	$800.00
13 hp Honda with 360gpm 3" Banjo Pump	1	$1,700.00	$1,700.00
3.5 hp Honda with 100gpm 2" Banjo Pump	1	$1,200.00	$1,200.00
2" Electric Valve Manifold: 4bolt, 12 Volt DC, 1.25 sec cycle	5	$355.00	$1,775.00
2" Electric Regulating Valve	1	$480.00	$480.00
3" Electric Valve	1	$966.00	$966.00
2" Flow Meters	2	$600.00	$0.00
3" Flow Meter	1	$800.00	$500.00
Wiring Harnesses	10	$12.00	$120.00
Electrical Box / Protection	1	$100.00	$100.00
2" Suction / Discharge Hose	100	$1.25	$125.00
Battery / Power Source	1	$100.00	$100.00
Controller (PLC)	1	$500.00	$0.00
Human Interface	1	$1,000.00	$0.00
PVC Fittings	1	$300.00	$500.00
Platform Skid	1	$150.00	$150.00
2" Schedule 80 Pipe	20	$1.75	$35.00
3" Schedule 80 Pipe	20	$3.50	$70.00
Software and Licensing	1	$750.00	$0.00
Assembly Labor	25	$300.00	$0.00
BAE Manufacturing	5	$200.00	$0.00
Expected Budget		$10,319.50	$8,621.00

Primary System Plumbing Components

3" Fittings (Banjo)			
3" X 4" POLY NIPPLE BANJO	Male Thread (course) to tank		11.97
3" PP FULL PORT BALL VALVE 6- BOLT DESIGN	3" Ball Valve		117.6
3" MALE ADPT X 3" MALE THR TYPE F PP CAM & GROOVE FITTING	Male to Male Banjo Cam		10.29
3" FEMALE COUPLER X 3" HOSE SHANK C PP CAM & GROOVE FITTING	Female Cam to Hose		15.26
3" FEMALE COUPLER X 3" HOSE SHANK C PP CAM & GROOVE FITTING	Hose to Female Cam		15.26
3" MALE ADPT X 3" FEMALE THR A PP CAM & GROOVE FITTING	Male Cam to Female th		8.04
3" X 4" POLY NIPPLE BANJO	To pump		11.97
3" X 4" POLY NIPPLE BANJO	From Pump		11.97
3" MALE ADPT X 3" FEMALE THR A PP CAM & GROOVE FITTING	Female thread to Male Cam		8.04
3" FEMALE COUPLER X 3" HOSE SHANK C PP CAM & GROOVE FITTING	Female Cam to Hose		15.26
3" MPT X 3" HB POLY STRAIGHT HOSE BARB	Hose to Male thread		8.28
3" POLY PIPE COUPLING BANJO	3" threaded cuppling		20.58
3" POLY PIPE TEE BANJO	For Secondary		38.59
3" MPT X 2" FPT POLY REDUCING BUSHING BANJO	Reduce to 2"		10.41
2" FEMALE COUPLER X 2" MALE THR B PP CAM & GROOVE FITTING	2" Cam		9.31
3" POLY PIPE 90 DEG ELBOW BANJO	To exit		33.06
3" MALE ADPT X 3" FEMALE THR A PP CAM & GROOVE FITTING	Exit Cam Hookup		8.04
3" FEMALE COUPLER X 3" HOSE SHANK C PP CAM & GROOVE FITTING	Female Cam to Hose		15.26
TOTAL			$ 369.19

KANAFLEX 390 SD / SUCTION & DISCHARGE HOSE

EXCELLENT CHOICE

fabric reinforced to prevent elongation

PSI	Size		Reel	Full Reel Cost	Cut Length Cost
KF114390	1 1/4"	100	100'	$2.25	$3.01
KF112390	1 1/2"	100	100'	$2.76	$3.70
KF2390	2"	100	100'	$3.18	$4.26
KF3390	3"	90	100'	$6.24	$8.36

Kanaflex 390 is an excellent all-weather suction/discharge hose • Use it where pressure is a factor. ⁿ Up to 50% lighter than conventional rubber hose • Highly resistant to temperature changes and deterioration by sun, ozone or mildew • Flexible in low temperature - Lends itself to working in tight spaces • EPDM tube with a thermal plastic helix for full suction • BLACK

KANAFLEX 300 SD / FERTILIZER SOLUTION EPDM TUBE - PVC HELIX

Part #	Size	PSI	Reel Size	Full Reel Cost	Cut Length Cost
KF1300	1"	50	100'	$1.16	$1.56
KF114300	1 1/4"	50	100'	$1.25	$1.68
KF112300	1 1/2"	50	100'	$1.48	$1.98
KF2300	2"	50	100'	$1.91	$2.57
KF3300	3"	43I	100'	$4.01	$5.37
KF4300	4"	38	100'	$11.46	$15.44

100' rolls of 2" & smaller UPSable

Kanaflex 300 is an excellent all-weather suction hose • Good for low pressure usage • Lightweight - low cost • Highly resistant to temperature changes and deterioration by sun, ozone or mildew • Flexible in low temperature - 100% EPDM tube - polyethylene helix • Smooth I.D. for maximum flow rates • GREEN & BLACK.

PVC SUCTION HOSE CLEAR WITH WHITE HELIX / CL112

Part #	Size	PSI	Reel Size	Full Reel Cost	Cut Length Cost
PVC34	3/4"	85	100'	$.56	$.75
PVC1	1"	85	100'	$.66	$.89
PVC114	1 1/4"	80	100'	$.68	$.91
PVC112	1 1/2"	70	100'	$.87	$1.17
PVC2	2"	65	100'	$1.25	$1.68
PVC3	3"	55	100'	$2.50	$3.35

Kanaflex CL112 is a high quality, flexible, long lasting PVC suction and discharge hose ideally suited for GENERAL purpose water suction • Smooth bore combined with smooth bending characteristics, makes for the fastest, most efficient transfer of fluids • Not chemical resistant • Clear tube with a white spiral.

6 – 2" Hose Connectors ($70)

3" POLY PIPE COUPLING BANJO	3" threaded cuppling		20.58
3" X 2" POLY REDUCER NIPPLE BANJO			7.93
3" POLY PIPE CAP BANJO			19.72
3" X 2" POLY REDUCING COUPLING BANJO			23.72
TU555 REGULAR PIPE DOPE 1 PINT			19.08
3" T-BOLT SS HOSE CLAMP 3.43"MIN/3.75"MAX DIA.			9.73
TOTAL			$ 100.76

Further Testing

Chemical Evaluation, Fluid Density

1. ***2,4-D Amine***
2. ***MCPA***
3. **Axial XL**
4. **Glyphosate**
5. **Dicamba**
6. **Paraquat**
7. **Valor**
8. **Brash/Weedmaster**; **2,4-D Amine + Dicamba**
9. **Gramoxone**
10. **Ammonium Sulfate (liquid)**
11. **Ammonium Sulfate (dry)**
12. **Clarity (dry)**
13. **Finesse (dry)**
14. **Olympus (dry)**
15. **ChemSurf or Squire (Non-Ionic Surfactant)**

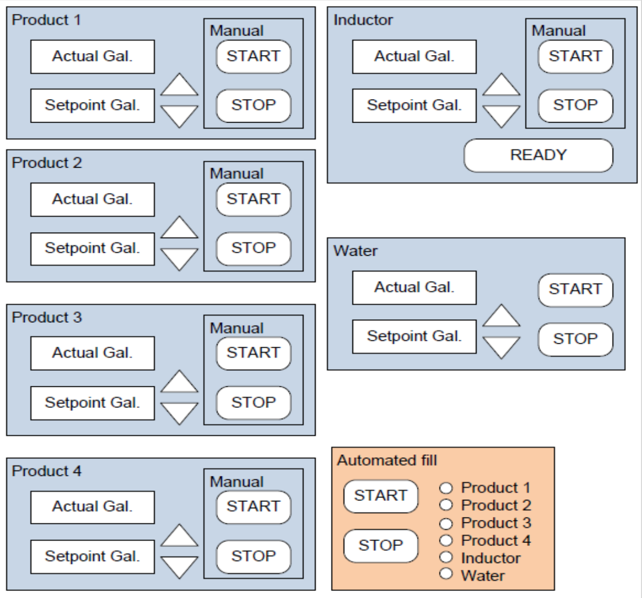
Dry indicates the substance will be slurried via the inductor

Further Testing

- Chemical Injection
  - Dye or conductivity testing
  - Chemical fluid analysis

Program Development

- HMI & PLC
  - Component response time
  - System communication



Concept provided by Microfirm Inc.

- Programming
  - Building code and debugging
  - Testing individual routines / components methodically

Troubleshooting

- Begin with individual pieces of code for each I/O
- Establish variables for each component
- Assemble code methodically and check

Manufacturing Skid

- Design securements and fixtures for components
- Finalize CAD drawing
- Outsource fabrication through BAE lab

Assembly

- Attach components robustly
- Enclose electronics
- Build wiring harnesses
- Ruggedized wiring and protective connectors
- Operator interface and work station accessibility

Final Testing and Validation

- Hookup IBCs to platform
- Connect carrier solution to platform
- Utilize PLC to operate chemical injection system
- Run batch load
- Verify chemical and carrier solutions were transferred accurately through mass balance calculations
- Record the batch summary from the interface

Acknowledgments

- **Microfirm, Inc**
- **Dr. Weckler**
- **Dr. Brown**
- **Dr. Storm**
- **Dr. Taylor**
- **Dr. Wang**
- **Biosystems Lab; Wayne Kiner**

Webpage

N2 Line Solutions

Home | N2 Line Updates | AutoTender 2000 | OK State BAE

Mission Statement

N2 Line Solutions focuses on providing reliable chemical mixing systems for the application industry. We offer our customers pristine quality products with the latest technological advancements in a simplistic fashion, at an affordable price.

Statement of Work

Microfirm, Inc. expects N2 Line Solutions to devise an automated chemical mixing and dispatch platform to be used in conjunction with a nurse trailer or filling rig. The automated system will meter a series of chemicals from the inputs entered in the electronic user interface on the system, deliver the chemical to the solution line filling the sprayer, and rinse the system to avoid contamination. The system will also have the capability to incorporate granular products via an eductor. This platform should allow the user to create tank mixes with little exposure and also change the chemicals quickly with little spillage. The team will determine whether it is best to utilize a self-contained, on-board platform pump and power supply, or utilize an existing sprayer-mounted pump. N2 Line Solutions will conduct most of the testing and design work in the Biosystems Lab and will have an automated system to meter chemical dosages accurately in May of 2012.

http://n2linesolutions.weebly.com/index.html